

# ELECTRICAL ENGINEERING TESTING

## Curve Plotting.

**Introduction.**—The practice of recording the results of any measurements or tests graphically, as well as in tabular form, in cases where this is possible, cannot be too strongly urged, and is a most important, as well as, in many cases, an indispensable operation. More especially is this the case with a large number of physical measurements, and particularly so with a majority of tests in Electrical Engineering. The practice of curve plotting, as these graphical representations may otherwise be termed, presents the following important features—

(a) It enables the nature of the variation of one quantity with another to be seen at a glance much more clearly than is possible by aid of a table of results.

(b) It enables errors in experimental observations, of which there are sure to be some, to be corrected comparatively easily, which in a majority of cases would be impossible from the table of results.

(c) In the case of the calibration of instruments it enables the law of that under test to be readily observed.

(d) It has the enormous advantage of enabling any intermediate value between those actually observed and tabulated, to be at once obtained accurately. This, it will readily be conceded, is the most important and valuable feature of all, and the ease, as well as the rapidity with which the operation of obtaining intermediate values can be accomplished, will be dependent on the scales chosen in originally plotting the curve in question.

It may therefore be profitable to indicate the mode of procedure in plotting curves, and with a view to exemplifying it, the results of a particular test are given in Table I., and the corresponding curve or graphical representation in Fig. 1. They relate to the determination of the Brake Horse Power (B.H.P.) of an electromotor and the corresponding value of its efficiency at each load.

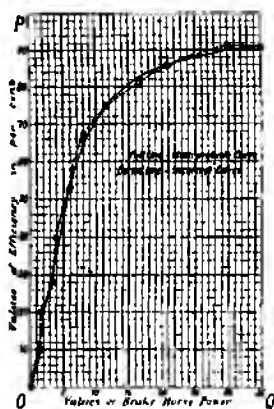


FIG. 1.

TABLE I.

B H P.	Efficiency,
1.5	10
1.75	20
2.5	28
4.0	40
6.0	51
8.0	67
11.5	75
16.5	81
21.0	86
30.0	91
35.0	91

In testing work generally at least six or eight different determinations throughout the range should be made, where possible, in order that the curve may be drawn more accurately. In most cases a curve constructed on three or four points only would, be practically useless and could not be depended on.

**Directions for Plotting.**—(1) Assuming that all the results have been worked out numerically and entered up in tabular form, the first thing to note is what two sets of quantities have to be plotted together, and secondly, the largest value of each set, for beyond this the scale need not extend.

(2) The left-hand vertical and bottom horizontal sides  $OP$  and  $OQ$  respectively of the squared sheet of curve paper are termed the axes and are rectangular. They intersect in a point  $O$  called

the *origin*. Distances measured vertically are termed *ordinates*, and those horizontally, *abscissae*.

(3) Carefully note which set of readings have to be plotted on the ordinates and which on the abscissae, and then choose the scales of the axes *OP* and *OQ* such that they are as long as possible and include the maximum values to be plotted. Also, if possible, arrange such that one of the smallest divisions represents a simple *whole number* of one digit. For example, if 33 was the largest number to be plotted and the side of the squared paper contained 100 divisions, let 1 division represent 0.33 only, whence 66 will give the 33; this is far more convenient a scale for future reference in obtaining intermediate values than 1 division representing 0.33 (i. e. 99 to give the 33 approx.). While it is a great advantage for the numerical length of the axes to be as large as possible, so as to enable the curve to be drawn larger and more accurately, the length should be decided by considerations of future reference to it for intermediate values as just mentioned.

(4) The axes must be numbered every 10th division, and under no circumstances with the numbers obtained from experiment.

(5) Write along each axis the nature of the quantity plotted on it.

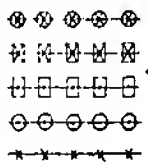
(6) Each point must be plotted by finding the point of intersection of the axes representing the two corresponding quantities under consideration at the moment and a distinctive mark there made.

(7) When all the points are plotted, a *mean curve*, as shown by the *full line*, Fig. 2, must be drawn through as many points as will allow of a *uniform line* being drawn.

Some points are always sure to lie on either side of this *mean line* and denote experimental errors. The object of the curve is to correct for these.

(8) In some tests, as for example in "characteristic" determinations with direct current generators, it often happens that curves cross one another and lie close together. In such cases they must be drawn *thin* and a different notation for the respective sets of points used, such as that represented in Fig. 2.

All confusion will thus be avoided.



## Calibration and Standardization of Electrical Measuring Instruments.

**General Remarks.**—This subject is perhaps one of the most important in connection with electrical testing, and we shall therefore devote some considerable attention to it. It will at once be obvious to any one, without any consideration, that a measuring instrument which is reading incorrectly, or one that has been calibrated so long ago that its present readings may not be true, is a useless instrument, or even worse than this, as one is unconsciously liable to take its reading as correct. The importance of correct reading and accurately calibrated measuring instruments cannot be over-estimated, for on their being so hangs the whole crux of further testing, the results of which would otherwise be quite worthless. This the author would emphasize most strongly, for it is unfortunately his experience, and no doubt that of many more like him, that the average experimentalist is only too ready to take the scale reading of any instrument as correct without in the least troubling himself as to whether it actually is so or not. This no doubt arises from the little extra trouble required to calibrate such instruments prior to starting some particular test.

Measuring instruments may change their constants and develop errors in their scale readings either from continued use, abuse, or in transit from one place to another, some of course being much more susceptible to alteration than others. Hence in all cases where it is desired to obtain accurate results and do good work, the instruments should be re-calibrated and re-standardized frequently, and a calibration curve drawn whenever possible with the date of the test inserted. At the very least six determinations should be made, wherever possible, but preferably ten or twelve, as it is not possible to draw a reliable calibration curve on less than six points. In all cases it is of the utmost importance to see that the connecting wires or cables do not magnetically affect the instruments, for it must be carefully remembered that a wire carrying a current, no matter whether it is straight or otherwise, acts as a magnet.



Such inductive effects will be minimized by running or twisting the "lead" and "return" together, when the two equal and opposite magnetic effects neutralize. An ordinary flexible twin-lead is non-magnetic externally, but it possesses a very small electrostatic capacity.

Instruments are usually calibrated by comparing their readings with those of very accurately calibrated standard instruments. *Simultaneous* readings must be taken on both to avoid errors due to variation in between. Ammeters are always connected *in series* and voltmeters are always connected *in parallel* with their standards.

In the calibration of voltmeters, the employment of keys in any of the branched or parallel circuits containing voltmeters to be calibrated is usually a source of inconvenience and should be avoided, for a key which places, say, a voltmeter of 1500 Ohms resistance in parallel with a similar instrument already reading, will cause this reading to decrease owing to the alteration of the P.D. at the terminals due to inserting such a low resistance meter, and the consequent reduction in the terminal combined resistance.

### (1) Calibration of an Ammeter by comparison with a Standard D'Arsonval Ammeter.

**Introduction.**—When a standard current measurer, such as a Kelvin standard balance or a potentiometer set, is not available for comparing the ammeter to be tested with, the following method of calibration may conveniently be employed. It consists in using a good reflecting D'Arsonval galvanometer in conjunction with a low resistance composed of platinoïd or other suitable material having a small temperature co-efficient of resistance, which should preferably be known. The resistance of the D'Arsonval galvanometer may conveniently be something like 2000 to 4000 times that of the low resistance to which it is shunted. The instrument, its scale, and the resistance should be permanently fixed and standardized carefully by means of a copper or silver voltmeter. Then if the current which produces a full scale deflection, with a certain known resistance in series with the galvanometer, is accurately known, the current producing any

other deflection with the same resistances will be very approximately in direct proportion and therefore at once known. Some slight corrections might be necessary for great accuracy when subsequently using these particular constants, due to alteration of resistance through change of temperature and to the deviation of the D'Arsonval readings from the direct proportional law, for which correction see Appendix, p. 480.

**Apparatus.**—Secondary battery *B* capable of giving the

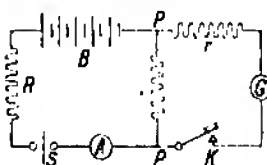


FIG. 3.

maximum current required; reflecting D'Arsonval galvanometer *G* (p. 569); switch *S*; key *K*; carbon rheostat *R* (p. 597); resistance box (*r*); ammeter *A* to be calibrated; low resistance *PP*, either of the form shown (p. 605), or simply a sheet of the metal.

**N.B.**—It is assumed that the galvanometer and low resistance in combination has been carefully standardized previously and now constitutes the standard D'Arsonval ammeter.

**Observations.**—(1) Connect up as in Fig. 3, and adjust the pointer of *A* to zero and the spot of light from *G* to the left-hand end of the scale used as a temporary or false zero in this test.

(2) Insert the proper resistance in (*r*) as given from the constants of standardization for the maximum current to be measured and corrected for the temperature of the room at the time of the test.

(3) With *K* large, close *S* and adjust the current through the ammeter to be calibrated to about  $\frac{1}{10}$ th of the maximum scale reading by means of *R*. Then note simultaneously its reading *A* and the deflection *d* on *G* when *K* is pressed.

(4) Repeat 3 for about ten different readings on *A* rising by about equal increments to the maximum with no decreasing of current.

(5) Repeat 3 and 4 for a similar descending set of the same readings on *G*, noting the corresponding ones on *A*, avoiding all increase of current, and tabulate your results as follows—

Name . . . . .		Date of Test . . . . .		
Ammeter tested: No. . . . .		Resistance ( $\rho$ ) = . . . . . Ohms.		
Temperature of Room = . . . . °C.		Resistance of ( $\rho$ ) = . . . . . Ohms at . . . . °C.		
Reading on Ammeter tested.	Deflection on D'Arsonval.	Corrected Readings of D'Arsonval.	True Current i.e. ( $\rho$ ) reduced ( $\alpha$ ) Amperes.	% Error of Ammeter tested.
Ascending A. . . . .	Descending A. . . . .	D. . . . .	(a) . . . . .	. . . . .

(6) Plot curves having values of true current ( $\alpha$ ) as abscissae and  $A$  as ordinates.

**Inferences.**—Enumerate any sources of error in ammeters generally. What can you infer from your experimental results? Why should the current be so carefully *increased only* in 4 above and *decreased only* in 5 above?

## (2) Calibration of an Ammeter by comparison with a Kelvin Composite Balance used as a Centi-ampere Meter.

**Introduction.**—The following is a convenient and ready means of calibrating any ammeter reading up to 1 ampere, employing a Kelvin composite balance used in the manner mentioned, as a standard for comparison. A complete description of the construction and manipulation of the instrument will be found on p. 554, to which a reference should be made and the constants obtained therefrom.

**Apparatus.**—Kelvin composite balance *K.B.* (p. 554); ammeter *A* to be tested; switch *S*; adjustable resistance *R* (p. 600, *et seq.*); source of current *C* at a P.D. of from 40 to 60 volts.

**Observations.**—(1) Connect up as in Fig. 4, adjusting both instruments carefully to zero. Make quite certain that the connections are as indicated.

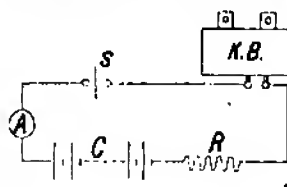


FIG. 4.

(2) Turn the switch in front of the balance to "volts" so as to place the fixed and movable fine wire coils in series with each

other and with the circuit. Now adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 556), so that the maximum current to be measured on *A* would give a reading on *K.B.* as nearly right across the scale as possible.

(3) With *R* as large as possible close *S* and obtain about  $\frac{1}{10}$ th of the maximum scale reading on *A* by varying *R*. Note this and simultaneously the corresponding position (*d*) of the slider of *K.B.*

(4) Repeat 3 for about ten different values of current on *A* (by altering *R*) rising by about equal increments to the maximum.

(5) Repeat obs. 4 for a similar set of descending values of current, and tabulate your results as follows—

Name . . . . . Date . . . . .  
 Composite Balance used: No. . . . . Constants . . . . . Ammeter tested . . . . .

Slider Reading ( <i>d</i> ).	True Amps. <i>K.A.</i>	Reading on <i>A</i> .		% Error of <i>A</i> .	Mean % Error.
		Ascending.	Descending.		

(6) Plot a calibration curve for the ammeter tested having readings on *A* as ordinates and "True Currents" as abscissae.

**Inferences.**—What sources of error are ammeters in general liable to? Can anything in particular be inferred from your experimental results?

### (3) Calibration of an Ammeter by comparison with a Kelvin Composite Balance used as a Hekto-ampere Meter.

**Introduction.**—The Kelvin composite balance can be used as a standard ammeter for the measurement of direct currents up to about 600 amperes, and hence any other ammeter can be readily calibrated by comparison with it. A description of the construction of the balance will be found on p. 554, together with the method of using it to measure heavy currents. In this connection it will be seen that the current to be measured passes through the thick fixed wire coils only, which act on the movable

coils of fine wire carrying a small auxiliary current from preferably an independent source of E.M.F. The accuracy therefore of the calibration will depend on the accuracy with which the current through the moving coils is measured, and this is a disadvantage in the use of the composite balance for current measurement.

**Apparatus.**—Kelvin composite balance *K.B.*; ammeter *A* to be tested; low reading accurately calibrated ammeter (*a*); rheostat *R* (p. 597) and *r* (p. 600); switches *S*<sub>1</sub> and *S*<sub>2</sub>; battery *C* capable of giving the current corresponding to the highest scale reading on *A*.

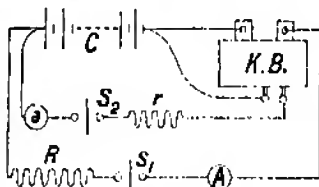


FIG. 5.

**Note.**—If a second battery, such as six small cells, is available the auxiliary current circuit may preferably be fed from it, for then this current will remain unaffected when the main current through *A* is altered.

**Observations.**—(1) Connect up as in Fig. 5 if only one battery is used, and adjust the pointers of *A* and *a* to zero, and also that of *K.B.* in the manner mentioned on p. 556. Make quite certain that the connections are as indicated in the diagram.

(2) Turn the switch on the balance (in front) to "Watts" so as to put the fine wire movable coils only in connection with the small terminals, and therefore in series with the auxiliary circuit.

(3) Adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 557) so that the maximum current to be measured on *A* would produce as nearly as possible a full scale reading on *K.B.*

(4) With *r* at its maximum close *S*<sub>2</sub> and adjust the current through the fine wire movable coil to its proper value, as given with the constant, by varying *r*. *Always make quite sure that it has this value before taking each reading on K.B.*

(5) With *R* large, close *S*<sub>1</sub> and obtain about  $\frac{1}{10}$ th of the maximum scale reading on *A* by varying *R*. Note simultaneously the reading on *A* and the position (*d*) of the slider of *K.B.*

(6) Repeat 5 for some ten different values of current on *A* (by altering *R*) rising by about equal increments to the maximum.

(7) Repeat obs. 6 for a similar set of decreasing currents and tabulate as follows—

NAME . . . . .		DATE . . . . .			
Composite Balance: No. . . . .		Constants used . . . . .		Current in Moving Coil . . . . .	Amps. . . . .
Ammeter tested . . . . .		Type . . . . .		No. . . . .	Range . . . . .
Mikler Reading (6).	True Amps. <i>K d.</i>	Reading on <i>A.</i>		% Error of <i>A.</i>	Mean % Error.
		Ascending.	Descending.		
— —					

(8) Plot "calibration" curves for the ammeter tested having readings on *A* as ordinates and true currents as abscissæ.

**Inferences.**—What sources of error are ammeters in general liable to? Can you infer anything in particular from your experimental results?

#### (4) Calibration of an Ammeter by comparison with a Kelvin Centi-ampere Balance.

**Introduction.**—Any ammeter reading up to 1 ampere can be readily calibrated by comparison with a Kelvin standard centi-ampere balance. A full description of this instrument, together with the table of constants, will be found on p. 516, and the method of using it is precisely the same as that of the composite balance used as a centi-ampere meter, except that there is no switch at all on the balance in question. The operator should refer to the Appendix (p. 516) for details in connection with the balance.

**Apparatus.**—This, with the exception of the balance, is precisely the same as is required for the corresponding calibration by the composite balance.

**Observations.**—These, together with the diagram of connection and the inferences, are precisely the same as for the test on p. 7 and will not therefore be repeated here. The operator must refer to the similar test using the composite balance.

### (5) Calibration of a Direct Current Ammeter. (Crompton Potentiometer Method.)

**Introduction.**—This method is a very convenient and accurate one for calibrating ammeters, and in it the measurements are referred to and obtained in terms of a standard Clark cell and standard resistance. The principle of the method is a direct application of Ohm's Law, and consists in measuring the fall of potential down an accurately known standard low resistance connected up in series with the circuit through which the current to be measured is passing. This fall of potential is measured in terms of the E.M.F. of the Clark's cell through the medium of the potentiometer, employing the principle of the Clark-Poggendorff method for comparing two or more E.M.F.'s. A detailed description of this will be found in a separate work by the author on *Practical Electrical Testing* for 1st and 2nd year students and others. The Crompton potentiometer is a specially arranged form of comparing instrument by means of which the calibration can be easily and quickly carried out. Before proceeding further the operator should refer to a detailed description of this piece of apparatus which will be found in the Appendix (p. 510) together with the method of using it. The present method possesses the all-important advantages that the measurements are all in terms of the Official Board of Trade standard—the Clark cell—that their accuracy is great, and without any very special means this can be obtained to at least 1 in 1000, and that the range is almost illimitable from 0 continuously up to maximums commonly met with in practice. The accuracy of the results in the present method is more particularly dependent on that with which the standard low resistance is known. The value of this must be such that the fall of potential down it due to the maximum current to be measured is not greater than 1.5 volts, while at the same time the carrying capacity must be such as to allow it to pass this current without sensible heating, which would thereby alter its resistance.

**Apparatus.**—Crompton potentiometer *P* (p. 510); secondary battery *B* capable of easily giving the maximum current required for a full scale reading on the ammeter *A* to be calibrated;

switch  $S$ ; one secondary cell ( $b$ ) for the "working cell" of the potentiometer; accurately known standard low resistance  $R$  (p. 605); sensitive D'Arsonval or moving coil galvanometer ( $g$ ) (p. 569); standard Clark cell  $E$ ; carbon rheostat ( $rh$ ) (p. 597).

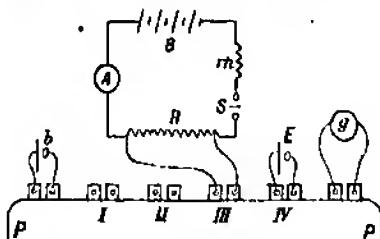


FIG. 6.

**Observations.**—(1) First place the levers of  $G$  and  $E$  (Fig. 208) on studs 14, and that of  $H$  on studs 1 or 2 for precaution. Now connect up as in Fig. 6, in which only the row of terminals on the potentiometer  $P$  is shown symbolically for brevity.

(2) Adjust the galvanometer  $g$  approximately, and  $A$  carefully, to zero, levelling them if necessary. See that a suitable low resistance standard  $R$  is employed, and one that will give a fall of potential at its ends not exceeding 1.5 volts ( $= A \times R$ ) for the maximum current to be used (*vide* p. 13).

(3) "Set the potentiometer" by the standard cell in the way described on p. 514, the contact lever  $H$  above referred to being on stud  $IV$ , thus inserting  $E$  (Fig. 6) in the circuit of  $g$ , which must be done so that its E.M.F. opposes that of  $b$ . Now close  $S$  and adjust  $rh$  so as to obtain about  $\frac{1}{10}$ th of the full scale reading on  $A$ .

(4) With the positions of the resistances  $G$  and  $G_1$  (Figs. 207 and 206) as found in 3, *unaltered*, turn the lever of  $H$  to stud  $III$  so as to throw into circuit with  $g$  the fall of potential down  $R$  which as seen is across terminals  $III$ . Now adjust the lever of the resistances  $R$  (Fig. 207) and the sliding key  $C$  so that no deflection occurs on  $g$  on pressing this latter.

**N.B.**—If it is impossible to get a balance owing to the deflection of  $g$  being always to one side, the P.D. across  $III$  is assisting, instead of opposing (as it should be) the fall due to  $b$  in the



stretched wire; the wires from *R* to *III* must then be interchanged.

3 If the lever at *E* is on stud 1 (literally 1000) and the slider *C* at 315 on the scale, the P.D. across *R* = .1315 volts and the true current  $A_1$  through *A* if *R* = 0.1 Ohm is  $\frac{.1315}{0.1} = 1.315$  amps.

Note simultaneously the readings on *P* and *A* when balance is obtained. Turn *H* to *IV* again and see whether the balance in obs. 3 still holds. If it does not, re-set *P*.

(5) Take about ten different scale deflections on *A* rising by about equal increments to the maximum by varying (*rk*) and repeat 4, noting the new values of *P* and *A*.

(6) Repeat 4 and 5 for a similar descending set of readings on *A* and tabulate your results as follows—

NAME . . . . . DATE . . . . .  
Clark Cell: No. . . . . Temperature = . . . ° C.; E.M.F. assumed = . . . volts.  
Potentiometer setting: *E* on . . . Cal . . . Standard Low Resistance *R* = . . . Ohms.

Ammeter Reading <i>A</i>	Potentiometer Reading		True P.D. across ( <i>R</i> ) <i>P</i>	True Current $A_1 = \frac{P}{R}$ amps.	Error of Ammeter ( $A_1 - A$ )	% Error.
	Stud of <i>E</i>	Position of Slider ( <i>C</i> )				

It should be carefully noted whether a "Clark" cell or "Carrhart-Clark" cell is being used before setting the potentiometer in 3, and that the assumed E.M.F. for this purpose at the particular temperature is correct, the temperature coefficient of E.M.F. being very different in these two cells (*vide* p. 643).

Standard Weston (cadmium) cells have an international value of E.M.F. of 1.0183 volts at 20° C., with a temperature coefficient of - 0.0000398 volt per rise of 1° C., between 0° and 10° C. In 1908, for a range of 0° C. - 40° C., Wolff obtained the relation giving the E.M.F. at *t* C., namely—

$$E_t = E_{20} - 0.0000406(t - 20) - (9.5 \times 10^{-7})(t - 20)^2 \\ = 1.0183\{1 - 0.0000398(t - 20)\} \text{ volts approx. (see table 643)}$$

(7) Plot calibration curves for the ammeter tested having values of *A* as ordinates and true amps  $A_1$  as abscissae.

Inferences.—What can you infer from your experimental results, and can you suggest any sources of error which might vitiate the results?

### (6) Determination of the "Constant" of a Galvanometer or Ammeter by Means of a Copper Voltameter.

**Introduction.**—From the results of a large number of tests it has been found that, using the necessary precautions, the constant of an electric current instrument can be obtained with certainty to within  $\frac{1}{10}\%$  of absolute accuracy by the electrolysis of copper. The voltameter (*V*) should consist of three or more pure copper plates dipping into a saturated solution of copper sulphate contained in a suitable glass or earthenware vessel, there being one, more "anode" than "cathode," and the two sets arranged alternately with an anode at each end. The plates should be as square as possible, and placed from  $\frac{1}{2}$ " to  $\frac{3}{4}$ " apart; if too close, polarization will take place when strong currents are used, and the current density (reckoned in amps. per sq. cm.) is too great. There should not be less than 30 sq. cms. per amp.; if there is, the plate surface will be too small and the deposit on the cathode irregular, some of it falling to the bottom of the vessel. The resistance of *V* will also become high and variable, due to the formation of copper oxide, and will give trouble in keeping the current constant. The solution should be a saturated one (sp. gr. 1.211) of pure copper sulphate crystals and distilled water, with 1% by vol. of strong sulphuric acid added, which is necessary to insure success. The vol. of solution should be about 1100 cc. per amp. The anodes may be made of about No. 18 S.W.G., and the cathodes or gain plates of No. 30 S.W.G. pure copper, all edges and corners being smooth and rounded. The electrochemical-equivalent (*Z*) of any substance, in this case copper = No. grams, deposited by 1 coulomb.

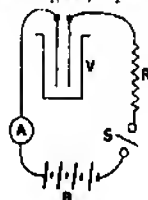


FIG. 7.

TABLE II.

Cathode area in sq. cms. per amp.	Values of ( <i>Z</i> ) for Copper.		
	5° C.	15° C.	25° C.
50	0.003250	0.003290	0.003280
60	83	87	86
100	88	84	85
150	87	81	80
200	85	79	77
250	83	78	76
300	82	78	72

**Apparatus.**—Voltmeter ( $V$ ); rheostat  $R$  (p. 597); switch  $S$ ; ammeter  $A$  to be standardized; secondary battery; drying cupboard  $D$ , not shown; acid bath.

**Observations.**—(1) Connect up as indicated in Fig. 7, and adjust  $A_0$  to zero. Light the gas jet under the steam boiler of  $D$ , after seeing that the latter contains enough water.

(2) Determine the necessary area of cathode, and hence the number of gain plates required for the current to be used, reckoning both sides in contact with liquid as the effective area of cathode.

(3) Carefully clean the cathodes all over with fine emery cloth until quite bright, then dust with a *dry clean cloth*, and *do not touch the part to be immersed with the fingers*. Clean the anodes if they look dirty.

(4) Carefully weigh the gain plates on a chemical balance to 1 mg., and note their weights ( $W_1$ ) grams.

(5) Insert the same area of trial plate to act as cathode, so as to adjust the current to the value required, then remove them, making sure that the + of battery is joined to anode.

(6) Insert the weighed gain plates, and at a convenient and noted instant of time switch on, quickly adjusting the current to its proper value.

(7) Keep it flowing for at least thirty minutes, and maintain it constant all the time by altering  $R$ , if necessary. (Note.—1.177 grams of copper (cupric) are deposited per amp.-hour approx.)

(8) Note the exact instant of switching off. Very carefully remove the gain plates so as not to scratch them, rinse in acidulated water to prevent the nascent copper oxidizing, then in clean water, and place in  $D$  to dry.

(9) When dry and cool re-weigh the gain plates and note the weights  $W_2$  grams.

(10) Repeat 2-9 for one or two other current strengths and tabulate as follows—

NAME . . . . .		DATE . . . . .			
Cathode Area = . . . sq. cms. per amp.		Temperature of Bath = . . . ° C. $\Sigma$ = . . .			
Weight of plates in grams.	Deposit $W$ ( $2W_2 - 2W_1$ )	Time in Secs. ( $t$ )	Reading of $A$ .	True Amperes $\frac{W}{Zt}$	% Error of $A$ .
Before $2W_1$	After $2W_2$				

### (7) Calibration of Direct Current Voltmeters. (Poggendorff's Method.)

**Introduction.**—The following method is a convenient one for enabling low-reading voltmeters up to about 3 or 4 volts to be easily and rapidly calibrated by comparison with one or two Clark's standard cells. Some convenient form of metre bridge, either circular or ordinary, is required. The principle of the method will be seen to be practically the same as the "Clark-Poggendorff" method of comparing two E.M.F.'s.

**Apparatus.**—Metre bridge of some convenient type, either the ordinary straight or circular form; secondary battery  $B$  giving an E.M.F. a little in excess of the maximum voltage to be recorded on the voltmeter  $V$  to be calibrated; key  $k$ ; carbon rheostat  $R$  (p. 597); sensitive galvanometer  $G$  (p. 572); high resistance ( $r$ ) of about 10,000 ohms; standard cell ( $S$ ) of known E.M.F. It will be observed that the metre bridge, of whatever form is used, is represented symbolically by  $PQ$  in Fig. 8, and if the general scheme of the connections is understood, there will be no difficulty with them when using any form of bridge.

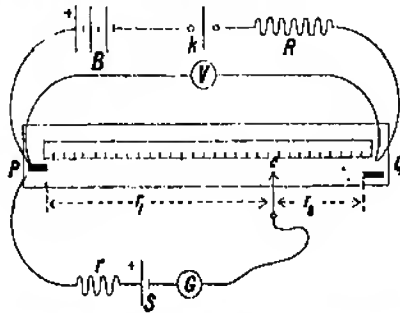


FIG. 8.

**Observations.**—(1) Connect up as in Fig. 8, adjusting  $V$  carefully to zero and  $G$  to about zero. See that like poles of  $B$  and  $S$

are connected to the same end  $P$ , when the respective E.M.F.'s will oppose one another.

(2) Adjust  $R$  to a high value and likewise ( $r$ ), which might preferably be about 10,000 ohms, and is merely for the purpose of preventing the standard cell  $S$  from sending but a very minute current when its circuit is closed at the tapping key or rolling contact  $C$ , which at first might be far from the correct position of balance. When  $C$  is moved to such a position that the deflection on  $G$  is small, ( $r$ ) may temporarily be cut out of circuit so as to make the sensitiveness of the test a maximum.

(3) Now close  $K$  and alter  $R$  so as to obtain about  $\frac{1}{10}$ th of the maximum scale reading on  $V$ .

(4) Find a position for  $C$  such that on making contact with the bridge wire by means of it, no deflection occurs on  $G$ ,  $r$  being manipulated as in obs. 2. Note the reading on the voltmeter  $V$  calibrated and the position of  $C$  where  $PC = r_1$  and  $QC = r_2$ .

(5) Re-insert  $r$  and repeat obs. 3 and 4 for about ten readings on  $V$  rising by about equal increments to the maximum.

(6) Calculate the true volts  $V_r$  from the relation—

$$V_r = \frac{r_1 + r_2}{r_1} \times \text{E.M.F. of standard cell,}$$

and tabulate your results as follows—

Name . . . . . Date . . . . .  
E.M.F. of Standard Cell = . . . Volts at . . . ° C.  $r = \dots$  Ohms } for reference only.  
 $G = \dots$  Ohms }

$r_1$	$r_1 + r_2$	Reading on $V_r$	True Volts $V_r$	% Error of Voltmeter tested.

Note.—The E.M.F. of a Clark's standard cell = 1.4340 legal volts at 15° C., and its E.M.F. at other temperatures may be found from the relation—

$$\text{E.M.F.} = 1.4340 \{1 - 0.0007 (t - 15^\circ)\} \text{ legal volts,}$$

where 0.0007 is the temperature coefficient of the cell and  $t$  = its temperature in degrees Centigrado. For a Carlhart-Clark cell the coefficient is 0.00038. For table of E.M.F.'s see p. 643.

(7) Plot a calibration curve of the voltmeter under test having values of  $V$  as ordinates and  $V_r$  as abscissae.

Inferences.—Does the accuracy of the above test depend on

anything in particular? Show how the relation given in 6 can be obtained and state any assumptions made in deducing it.

### (8) Calibration of a Voltmeter by Comparison with a Standard D'Arsonval Voltmeter.

**Introduction.**—The method may conveniently be employed for calibrating a voltmeter when neither a Kolvin *standard balance* nor a "potentiometer set" is available for use as a standard with which to compare the instrument under test. In the present case a fairly sensitive and good form of D'Arsonval galvanometer combined with a high resistance placed in series constitutes the standard voltmeter which together with its scale is permanently fixed up. The arrangement is very carefully standardized and its *constants* found with the aid of a Clark's standard cell and Clark's potentiometer method (p. 16), and thus a reliable standard voltmeter is obtained.

If the voltage which produces a full scale deflection with a certain resistance in series with the instrument at a given temperature is known, then that causing any other deflection under the same conditions will be in direct proportion and therefore at once known. For considerable accuracy some small corrections would be necessary in using these constants at some other time owing to the difference in temperature altering the resistances of the galvanometer coil and those in series with it, and to the D'Arsonval not exactly fulfilling the direct proportional Law, for which correction see p. 490.

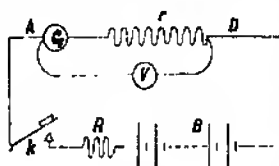


FIG. 9.

The D'Arsonval and its resistance can be arranged in one of two ways—(a) as represented in Fig. 9, assuming that a sufficiently high adjustable known resistance for placing in series with it is available. If then the "figure of merit" of  $G$ , i.e. the am-

peres (a) per scale division, is accurately known, the extra high resistance (r) necessary to be placed in series with it so that the

required maximum voltage applied to  $AD$  (Fig. 9) may produce a full scale deflection on  $G$ , can be found by Ohm's Law as follows—

• If  $(d)$  = the maximum scale reading to be obtained by a maximum voltage  $V$ , then if  $(g)$  = the resistance of the galvanometer  $G$ , we have  $(r + g) = \frac{V}{\frac{V}{ad}} = \frac{V}{ad}$

$$\therefore r = \left( \frac{V}{ad} - g \right) \text{ ohms.}$$

(b) If  $G$  is very sensitive and sufficient resistance is not available the arrangement in Fig. 10 may be used,  $r$  now taking the form of two resistance boxes  $r_1$  and  $r_2$ .

In this case  $r_1$  will be small, compared with the resistance of  $G$  and with  $(r_1 + r_2)$ , and this sum large compared with the resistance of  $V$ , the voltmeter to be calibrated.

If  $V$  and  $v$  are the voltages across  $HD$  and  $r_1$  respectively and  $(g)$  the resistance of  $G$ , whose "figure of merit" is  $(a)$ ,

$$\text{then } V : v = r_2 + \frac{r_1 g}{r_1 + g} : \frac{r_1 g}{r_1 + g}$$

and if  $(d)$  has the same meaning as before  $v = adg$ ,

$$\text{whence } V \frac{r_1 g}{r_1 + g} = adg \left( r_2 + \frac{r_1 g}{r_1 + g} \right)$$

assuming  $r_1$  to be negligibly small compared with  $g$  and  $r_2$  we have  $r_2 = \frac{adg}{V}$  approximately, which is obvious from a consideration of Ohm's Law.

Referring to Fig. 8 it will at once be seen that discarding the cell  $S$ , the standard D'Arsonval  $G$  with its extra resistance  $r$  may be employed to actually measure the P.D. between  $P$  and  $C$ , whence knowing the ratio of  $PQ$  to  $PC$  the true volts corresponding to any reading on  $V$  (Fig. 8) can at once be obtained. Thus the arrangement just referred to practically brings us to that shown in Fig. 10.

**Apparatus.**—Secondary battery  $B$  of a sufficient number of cells

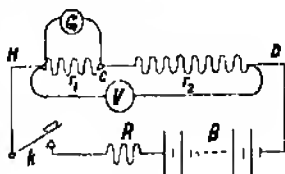


FIG. 10.

to give the highest reading on the voltmeter ( $V$ ) to be calibrated; a fairly high resistance D'Arsonval galvanometer  $G$  (p. 569); spring tapping key  $k$ ; one or two high resistance boxes  $r_1$  and  $r_2$ ; variable unknown high resistance rheostat  $R$ ; this latter, however, will be of no use if the resistance of the rest of circuit is very high, and in this case the voltage due to  $B$  will have to be varied by altering the number of cells in the battery.<sup>1</sup>

**Observations.**—(1) Connect up as shown in Fig. 10, which latter arrangement will be found to be the one most common in practice. Adjust the spot of light of  $G$  to the left-hand end of the scale as a temporary or false zero so as to obtain a full scale deflection up to the other end for the maximum voltage to be measured.

(2) Insert the proper resistances in  $r_1$  and  $r_2$  as given from the constants of standardization for the maximum voltage to be measured and corrected for the temperature of the room at the time of the test.

(3) Close  $k$  and adjust  $R$ , or alter the number of cells in  $B$  so as to obtain about  $\frac{1}{10}$ th of the maximum scale reading on  $V$  and note simultaneously the readings on  $V$  and  $G$ .

(4) Repeat 3 for about ten different readings on  $V$  rising by about equal increments to the maximum.

(5) Repeat 3 and 4 for a similar *descending* set of the same readings on  $G$ , noting the corresponding ones on  $V$ , and tabulate your results as follows—

NAME . . . . . DATE . . . . .  
 Voltmeter: No. . . . . Type . . . . . Resistance  $r_1$  = . . . Ohms  
 . . . . .  $r_2$  = . . . " "  
 . . . . .  $G$  = . . . Ohms at . . . °C.  
 Temperature of room = . . . °C. Resistance of  $G$  = . . . Ohms at . . . °C.

Reading in Volts on Voltmeter tested.		Deflection on D'Arsonval $G$ .	True Voltage, i.e. $B$ reduced to Volts.	% Error of Voltmeter tested.
Ascending $V$ .	Descending $V$ .			

<sup>1</sup> Instead of the variable high Resistance rheostat ( $R$ ) shown in tests 8-11 which may not be available, the following arrangement for varying the voltage across the parallel combination of voltmeter tested and standard, will be found convenient, namely—connect two variable lamp resistances  $R_1$ ,  $R_2$  in series across the supply and shunt one of them ( $R_1$ ) with the voltmeter and standard in parallel, the lamps of each rheostat being operated in parallel and being for a voltage = to that of the supply. Then by keeping 1 lamp in  $R_1$  and varying  $R_2$  the volts across  $R_1$  can be varied from  $\frac{1}{2}$  that of the supply to its full value, while by keeping 1 lamp in  $R_2$  and varying  $R_1$  the volts across  $R_1$  can be varied from  $\frac{1}{2}$  that of the supply to 0; thus covering the full range of supply volts on  $R_1$ .



(6) Plot "calibration curves" having values of true voltage ( $e$ ) as ordinates and  $V$  as abscissae.

**Inferences.**—Enumerate any sources of error in voltmeters generally. State clearly what you can infer from the results of your tests.

### (9) Calibration of a Voltmeter by Comparison with a Kelvin Composite Balance used as a Voltmeter.

**Introduction.**—The composite balance when used in conjunction with separate anti-inductive resistances may be conveniently employed as a standard direct or alternating current voltmeter capable of measuring pressures up to about 600 volts. The following method assumes the use of such an instrument, and the reader should refer to p. 554, *et seq.*, for the construction and mode of using this form of balance and for the table of constants and sensibilities.

**Apparatus.**—Adjustable, fairly high resistance  $R$  (p. 603); switch  $S$ ; voltmeter  $V$  to be calibrated; Kelvin Composite Balance  $K.B.$ , with its non-inductive resistance  $r$  (p. 553); battery of secondary cells capable of giving the maximum voltage to be used, which we therefore assume to be direct.

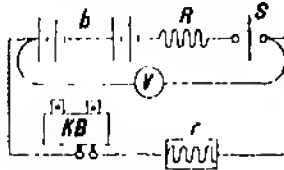


FIG. 11.

**Observations.**—(1) Connect up as in Fig. 11, adjusting both instruments carefully to zero, and make quite certain that the connections are as indicated.

(2) Turn the switch in front of the balance to "Volts" so as to place the fixed and movable fine wire coils in series with one another across the terminals. Observe that the anti-inductive resistance  $r$  is numbered the same as, and therefore belongs to the balance in use, and make quite sure of having the correct resistances in it in use (p. 556).

(3) Adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 556), so that

the maximum voltage to be measured on  $V$  would produce as nearly as possible a full scale reading on  $K.B.$

(4) With  $R$  as large as it can be, close  $S$ , and obtain about  $\frac{1}{10}$ th of the maximum scale reading on  $V$  by altering  $R$ . Note simultaneously the reading on  $V$  and position ( $d$ ) of the slider of  $K.B.$

(5) Repeat 4 for some ten different values of voltage on  $V$  (by altering  $R$  or the number of cells in the battery) rising by about equal increments to the maximum.

(6) Repeat obs. 5 for a similar set of decreasing voltages, and tabulate your results as follows—

NAME . . . . . DATE . . . . .  
Composite Balance: No. . . . . Constants . . . . . Voltmeter tested. . . . . Temp. = . . . °C.

Slider reading d.	Volts K.d.	Corrected Volts $V_T$ .	Reading on $V$ .		% Error of $V$ .
			Ascending	Descending	

N.B.—The values  $V_T$  are the readings on the standard corrected for temperature.

(7) Plot a calibration curve for the voltmeter tested having readings on  $V$  as ordinates and true volts  $V_T$  as abscissae.

**Inferences.**—What sources of error are voltmeters in general liable to? Can anything in particular be inferred from the above results?

### (10) Calibration of a Voltmeter by Comparison with a Kelvin Centi-ampere balance used as a Voltmeter.

**Introduction.**—The Kelvin Standard Centi-amperes balance when used in conjunction with extra anti-inductive resistances constitutes a most convenient standard voltmeter with which to compare any other voltmeter to be calibrated, up to about 800 volts.

For larger voltages, up to 2500 volts, special non-inductive high resistances are provided for inserting in series with the coils of the instrument. The combination then constitutes a standard voltmeter by means of which any other voltmeter, either for direct or alternating currents, reading up to 2500 volts, can be calibrated, by comparison, in the ordinary way.

A complete description of this balance, together with the

method of using it, will be found on p. 516 *et seq.*, where the table of constants is given.

In the present test the apparatus, observations and inferences are precisely similar to that of the corresponding calibration by means of the composite balance used as a voltmeter, the centi-ampere balance being substituted for this latter. They will consequently not be repeated here, but may be seen on p. 31.

### (11) Calibration of a Direct Current Voltmeter. (Crompton Potentiometer Method.)

**Introduction.**—The method is a very convenient and accurate one for the purpose, and consists in calibrating the voltmeter to be tested in terms of the E.M.F. of a Clark's standard cell, a known fraction only of the voltage applied to the instrument being actually compared with the standard E.M.F. The principle of the method is identical with that of the "Clark-Poggendorff" method for comparing two or more E.M.F.'s, a full description of which will be found in a separate work, by the author, on *Practical Electrical Testing*, for 1st and 2nd year students and others. The Crompton Potentiometer is a specially arranged form of comparing instrument by means of which the calibration can be easily and quickly carried out. A detailed description of it will be found on p. 510, to which the reader should in the first instance refer. There are three extremely important features in connection with the present method, using the potentiometer; firstly, the enormous range of applicability, for the instrument can be used equally well in the measurement of current and resistance as well as voltages from 0 to almost any practical amount; secondly, the measurements are in terms of the official Board of Trade Standard—the Clark cell—though any other standard can be used; thirdly, the accuracy is great and under ordinary conditions the measurements are accurate to at least  $\frac{1}{5}\%$ , and with care, using a very accurately adjusted instrument, accuracy to something like  $\frac{1}{100}\%$  can be obtained. In this form of potentiometer the highest voltage which can be compared directly is 1.5 volts, and hence the fractions employed of all higher pressures to be measured must fall within this limit.

**Apparatus.**—Crompton potentiometer *P* (Fig. 208); secondary battery *B* capable of giving the maximum voltage required for a

full scale reading on the voltmeter  $V$  to be calibrated; key or switch  $S$ ; one secondary coil ( $b$ ) for the "working coil" of the potentiometer; "volt box," i.e. divided resistance  $ad$  for obtaining a fraction (less than 1.5 volts) of the total P.D. to be measured (p. 521); sensitive D'Arsonval or moving coil galvanometer ( $G$ ) (p. 569); standard Clark cell  $E$ ; fairly high resistance rheostat  $R$  (p. 603). See footnote, p. 20.

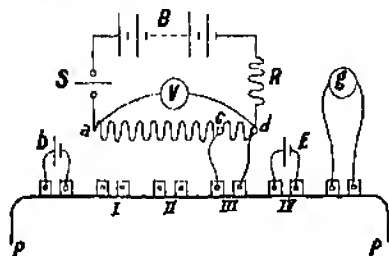


FIG. 12.

**Observations.**—(1) After placing the levers of  $G$  and  $E$  on studs 14 and that of  $H$  on studs 1 or 2 for precaution, connect up as in Fig. 12, in which only the row of terminals on the potentiometer  $P$  is shown, symbolically, for the sake of brevity.

(2) Adjust the spot of light of the galvanometer to somewhere about zero on the scale, and the resistance  $ad$  and  $cd$  in the "volt box" so that  $cd = \frac{1}{10}$  of  $ad$ , supposing, of course, that not more than 150 volts is across  $ad$ . Carefully level and adjust  $V$  to zero if it requires it.

(3) "Set the potentiometer" by the standard cell in the way described on p. 514, the contact lever  $H$ , Fig. 208, p. 512, being on stud  $IV$ , thus inserting  $E$  in the circuit of  $g$  in such a way as to oppose that of  $b$ , close  $S$ , and adjust  $R$  so as to obtain the full scale deflection on  $V$ .

**Note.**—This last operation will only be possible when  $R$  is comparable with the parallel resistance of  $ad$  and  $V$ . If both these are very high then altering  $R$  will have very little effect on the reading of  $V$  unless  $R$  is high also in comparison.

(4) With the positions of the resistances  $G$ , and  $G$  (Fig. 208, p. 512), as found in 3, *unaltered*, turn the lever of  $H$  to studs

*III* so as to throw into circuit with *g* the  $\frac{1}{100}$ th part of the voltmeter P.D., which was across terminals *III*. Now adjust the *lever* of the resistances *E*, Fig. 208, and the sliding key *C*, Fig. 208, so that no deflection occurs on pressing this latter.

**N.B.**—If no balance can be obtained owing to there being no reversal of deflection on *g*, the fractional P.D. across *III* is assisting instead of opposing (as it should be) the fall of potential due to (*b*) in the stretched wire. The wires from *cd* to *III* must then be interchanged. If the lever at *E* is on stud 12 (literally 12,000) and the slider *C* at 625 on the scale, the voltage across *ad*, i.e. at the terminals of  $V = 126.25$  volts. Note these positions on *PP*, and simultaneously the reading *V* on the instrument to be calibrated.

(5) Reduce *V* by about  $\frac{1}{10}$  either by cutting out cells in *B* or by altering *R* or both, and repeat 4, noting the new values of *V* and *PP*. Turn *H* to *IV* for a moment and see whether the balance in obs. 3 still holds, if not re-set as in obs. 3 above.

(6) Repeat 4 and 5 for some ten or twelve different readings on *V decreasing* by about equal amounts to the lowest.

(7) Repeat 4 to 6 for a similar *ascending* set of observations, and tabulate your results as follows—

Name . . . . . Date . . . . .  
 Clark Cell: No. . . . . Temperature = . . . ° C E.M.F. Assumed = . . . Volts.  
 Volt Box: Fraction of total used  $\frac{ad}{cd}$  = . . . . . Potentiometer setting *R* on . . . . . Cal . . . . .

Voltmeter Reading <i>V</i> .	Potentiometer Reading.		True Volts Across.		Error of Voltmeter $V_1 - V_2$ .	% Error.
	Stud of <i>R</i>	Position of Slider <i>C</i> .	Fraction $\frac{ad}{cd}$	Voltmeter $V_1 = \frac{ad}{cd} V_2$ .		

As it may sometimes be the case that a Carhart-Clark and not a Clark's standard cell has to be used, care should be taken that the E.M.F. assumed at the particular temperature is correct, the temperature coefficient of E.M.F. being very different in the two cases (*vide* pp. 17 and 643).

(8) Plot a calibration curve for the voltmeter tested having values of *V* as ordinates and true volts  $V_1$  as abscissae.

**Inferences.**—What can you infer from the results of your test? Are there any sources of error which might vitiate the results?

## (12) Calibration of a High Tension Alternating Current Voltmeter.

**Introduction.**—In the ordinary high tension systems of distribution of electrical energy by alternating currents, the average working pressures are about 2000 or 2500 volts. The "electromagnetic" and "hot wire" types of voltmeters are unsuitable for measuring such high pressures, which can best be dealt with by means of a third class of instrument known as the electrostatic voltmeter, a description of two forms of which will be found in the Appendix (p. 562).

These instruments are almost universally employed for measuring alternating current pressure, and they have the all-important advantage of being unaffected by variation of frequency. Owing usually to the difficulty experienced in obtaining direct current pressures of the above magnitude for testing purposes, alternating currents have nearly always to be employed for calibrating high tension voltmeters. Thus it will be seen that none of the preceding methods are available in the present case, but the calibration can be effected by what may be termed the "fractional potential difference" method, using an accurately calibrated low tension electrostatic voltmeter for comparison in the manner to be described later.

This low tension voltmeter, which may conveniently be one of Lord Kelvin's multi-cellular electrostatic instruments reading to, say, 150 volts, should be very carefully calibrated by one of the preceding methods—preferably the *potentiometer*, one using a Clark's cell as a standard of E.M.F. and direct current pressures of course. For accurate work, however, the following remarks should be observed. In these voltmeters the movable needle system is usually aluminium and the fixed system brass, whence owing to aluminium being electro-positive to brass, the instrument will read from 0.2 volt to 0.3 volt too low when the +ve pole of the direct current source is connected to needle, and the same amount too high if the —ve is joined to the needle system instead. In calibrating this low reading voltmeter by the potentiometer, it should be connected up through a reversing key to the rest of the apparatus and the mean of the readings, before

and after reversing the polarity on its terminals, taken as the correct one for alternating currents, since when used with such the above-named error does not occur. Again with direct currents an electrostatic voltmeter passes no current, but owing to it possessing a perfectly definite though very small capacity, it will behave like a condenser with alternating currents, i.e. a pulsating or "charge and discharge" current will be set up in its circuit. Thus it will be seen that if, as in the present method, such an instrument is shunted across part of a circuit carrying an alternating current, the current in the voltmeter branch may be quite comparable with that in the main circuit, in other words the P.D. between the points to which it is shunted would be lowered somewhat by the voltmeter, and  $\therefore$  would not bear to the whole P.D. the ratio of the resistance of the two portions of the circuit. To avoid such an error the resistance of the main circuit should be such that the maximum pressure to be used sends a sensible current such as from  $\frac{1}{2}$  to  $\frac{1}{4}$  an ampere through it, which will consequently be very large compared with the current in the voltmeter branch. Thus the presence of this latter will not affect the value of the P.D. between the two points to which it is applied, and consequently the ratio of the whole P.D. to the fraction thus tapped will equal the ratio of the whole resistance to the fraction across which the electrostatic voltmeter is placed.

**Apparatus.**—Alternator *A*, capable of supplying a low pressure, and of being driven at any required speed by a direct current, electromotor (preferably), or other prime mover, its exciting circuit *E* consisting of the field coils of *A* (shown), together with switch, rheostat, ammeter and source of

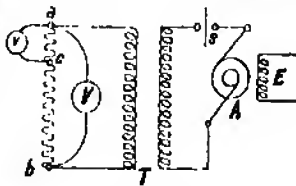


FIG. 13.

excitation (not shown), but which can be varied so as to vary the E.M.F. of *A*; step-up transformer *T* capable of increasing the pressure from that of *A* to the maximum required for a full scale reading on the high tension voltmeter *V* to be calibrated;

low tension electrostatic voltmeter ( $v$ ) (p. 562), reading to say 150 volts, and which has been previously carefully calibrated by reference to a standard Clark cell on the potentiometer; switch  $x$ . A divided non-inductive high resistance ( $acb$ ) capable of standing the highest pressure to be used on  $V$ , and of carrying an appreciable current, say of the order of  $\frac{1}{4}$  to  $\frac{1}{2}$  an ampere continuously without excessive heating.

**Caution.**—Under no circumstances whatever is any part of the high tension circuit to be touched while "alive," and the india-rubber gloves are to be worn throughout the test by the operator reading the electrostatic voltmeters.

**Observations.**—(1) Connect up as in Fig. 13, and carefully level and adjust the pointers of  $V$  and  $v$  to zero. For the high tension side use well-insulated wires for the connections, and keep them in mid-air as much as possible.

(2) If the voltmeter  $V$  to be calibrated reads up to, say, 2500 volts, and  $v$  to only 150 volts, place this latter across a convenient fraction ( $ac$ ), say  $\frac{1}{10}$ th of the whole non-inductive resistance ( $ab$ ), which in this case may conveniently be something like 5000 Ohms.

(3) Start the alternator  $A$ , close  $s$ , and then adjust the speed and excitation so as to obtain the lowest scale reading on  $V$ . Note simultaneously that on ( $v$ ) also.

(4) Repeat 3 for ten or twelve different voltages on  $V$ , rising by about equal increments to the maximum, and tabulate as follows—

Name . . . . . Date . . . . .  
H.T. Voltmeter tested: No. . . . . Type . . . . . Range . . . . . Made by . . . . .  
Whole resistance  $ab = \dots$  Ohms. Fraction used  $ac = \dots$  Ohms. Ratio  $\frac{ab}{ac} = \dots$

$V$ .	Reading on $v$ .		True voltage $V_1 = \frac{ab}{ac} V_1$	% Error of meter tested $100(V - V_1)$	Mean Error.
	$v$ .	(Corrected $V_1$ )			

(5) Plot a calibration curve for the high tension voltmeter having values of  $V$  as ordinates and true volts  $V_1$  as abscissae.

**Inferences.**—Enumerate what you consider to be the advantages and disadvantages of electrostatic voltmeters.



### (13) Complete Test of both Direct and Alternating Current Ammeters and Voltmeters for the various sources of Errors.

**Introduction.**—The principle involved in the action of any type of ammeter or voltmeter will come under one of the following heads—

- (1) *Heating* effect of the current or P.D. to be measured.
- (2) *Electrostatic* effect of attraction or repulsion between fixed and movable conducting surfaces, close to, but insulated from one another, when electrified to opposite potentials.
- (3) *Electro-magnetic* effect of the current in a coil of wire on iron or *vice versa*.

(4) *Electro-dynamic* action of the current in one part of circuit on the same current in another part of that circuit, causing electro-dynamic attraction or repulsion between the two.

There are briefly eight principal sources of error to which ammeters and voltmeters in general are liable, namely—

- (a) Error in the calibration owing to the standards employed in the two cases being different.
- (b) Error through a partial demagnetization of the permanent field, causing an alteration in the sensibility, in the case of permanent steel magnet instruments.
- (c) Error caused by the sensibility of the instrument being temporarily altered by external magnetic influence.
- (d) Error due to a current producing a different deflection depending on the magnitude of the current previously measured compared with the one in use at the time.
- (e) Error due to the instrument giving a different scale reading for different directions of the same current.
- (f) Error in the case of voltmeters due to alteration of the resistance of the instrument caused by change of temperature, whether from the room or passage of the current.
- (g) Error in alternating current instrument due to alteration of frequency.

(h) Error due to friction at the pivots in all classes.

Error (a) applies to all four classes of instruments, and cannot very well be remedied except by re-calibration.

It is clear that classes 1 and 2, being entirely non-magnetic,

may be dismissed as not being liable to magnetic errors. Classes 3, however, and 4, which latter type may or may not contain iron, are liable to large errors arising in the case of direct currents from the retentivity of the iron used (error *d*), or magnetic hysteresis, and from the proximity of, and the external magnetic effect of currents in neighbouring wires and of magnets (error *c*). In the case of alternating currents from hysteresis, eddy currents in the metal work about the instrument re-acting on the coil, and change of frequency (error *y*) in the alternating current.

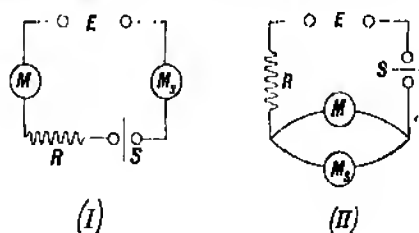


FIG. 11.

In this latter class of work the instruments should contain no iron at all, and very few metal fittings. In good direct current instruments where iron is a necessity, it should be *very soft*, and well laminated, and there should not be much of it.

**Apparatus.**—Ammeter or voltmeter *M* to be tested; suitable variable rheostat *R*, which in the case of the ammeter test must be capable of carrying the maximum current required by *M*, and in the case of the voltmeter test must have a large resistance so as to be quite comparable with that of *M*; switch, or key *S*; source of electrical supply *E*, whether direct, or alternating current; standard accurately calibrated ammeter or voltmeter *M<sub>s</sub>*, which must not contain any iron, and preferably no metal fixings.

**N.B.**—The standard *M<sub>s</sub>* may be either a Kelvin standard balance (p. 646); Siemens electro-dynamometer (p. 577); Cardew, or electrostatic voltmeter (p. 662), preferably the latter, which not only is non-magnetic, but also has no temperature error. See footnote, p. 20.

**Observations.**—(1) If an ammeter is being tested, connect up as in Fig. 14 (I), but if it is a voltmeter, then as in Fig. 14 (II). Care

fully adjust the pointers of  $M$  and  $M_s$  to zero if they require it, levelling them also when necessary so that all moving parts can move quite freely. Place  $M$  and  $M_s$  at some distance apart so that there can be no possibility of one affecting the other. Also run the connecting leads close together so that their magnetic effect due to the current in them may not affect the instruments.

(2) ERROR DUE TO EXTERNAL MAGNETIC EFFECT. (A.)

With  $R$  at its maximum, close  $S$ , and obtain about  $\frac{1}{2}$  full scale reading on  $M$ . Note the corresponding reading of  $M_s$ , which must be kept quite constant and steady when no magnet is near. Now move a powerful permanent magnet in a plane perpendicular to the axis about which the moving system of  $M$  oscillates and passing through its centre, the axis of the magnet pointing to  $M$  always, and its pole nearest to  $M$  being moved so as to be always at about 12" away from  $M$ . Note the alteration (if any) of the reading of  $M$ .

(3) Repeat 2 for a full scale deflection on  $M$ .

(4) Repeat the last part of 2, pertaining to the motion of the magnet, with no current flowing, i.e.  $S$  open, and tabulate your results as shown in the table below.

N.B.—The magnet must not be allowed to affect  $M_s$  in any way, and the latter must be far enough away to ensure that this is the case.

If  $M$  is an alternating current instrument, and an alternating supply is being used, the frequency must be maintained constant in 2 and 3 above, as well as the reading of  $M_s$  in the particular test.

(5) ERROR DUE TO RETENTIVITY OR RESIDUAL MAGNETISM. (B.)

With  $R$  at maximum, close  $S$ , and carefully take a gradually increasing set of about ten simultaneous readings on  $M$  and  $M_s$  from the lowest to full scale, by gradually diminishing  $R$ , gently tapping the instruments to eliminate any pivot friction.

(6) Repeat for a similarly obtained decreasing set, the same scale reading of the standard  $M_s$  being obtained when descending as was obtained on ascending. Tabulate your results as indicated in the following table.

N.B.—This test of course only applies to direct current instruments, and the error in question may amount to over 20%.

Standard instrument used: Type . . . No. . . . Maker . . . Constant . . .  
 Instrument tested: Type . . . No. . . . Maker . . .

A. External Magnetism.			B. Retentivity or Residual Magnetism.				
Position of influencing magnet.	Reading on		Reading on			Z Error.	Frequency (constant) of alternating current used.
	$M_s$	$M$	$M_s$ ascending and descending.	$M$ ascending.	$M$ descending.		

(7) ERROR DUE TO VARIATION OF "FREQUENCY" WITH  
 ALTERNATING CURRENT INSTRUMENTS. (C.)

Close  $S$ , and adjust  $R$  to give some convenient scale deflection on  $M$  and  $M_s$ , which latter must be kept constant by means of  $R$ . Now vary the frequency, by altering the speed of the alternator if this is under control, from the smallest to the greatest possible so as to obtain about ten different values, and note the simultaneous readings on  $M$  and  $M_s$  at each.

(8) ERROR DUE TO EDDY CURRENTS IN METAL FIXINGS WITH  
 ALTERNATING CURRENTS. (D.)

If either  $M$  or  $M_s$  possesses a moving coil, the terminals of which can be got at to send a current through this coil only of the instrument, as in either a Kelvin balance, Siemens dynamometer, or Parr direct reading dynamometer instruments. Proceed as follows—Adjust the pointer of this instrument carefully to zero, and send the maximum alternating current through this moving coil alone, noting whether it deflects. If it does, eddy currents are being set up in the metal fixings and react on the moving coil causing it to deflect.

(9) Repeat 8 for the same current at different frequencies, and tabulate your results as in the following table—

Standard instrument used: Type . . . No. . . . Maker . . . Constant . . .  
 Instrument tested: Type . . . No. . . . Maker . . .

C. Effect of Frequency.			D. Eddy Currents.		
Frequency in per cent.	Reading on		Frequency in per cent.	Reading on	
	$M_s$	$M$		$M_s$	$M$

## (10) ERROR DUE TO REVERSAL OF CURRENT THROUGH THE INSTRUMENT. (E.)

Connect up as shown in Fig. 14, but instead of connecting  $M$  directly in series as shown, join it up now to the circuit through a reversing switch or key, so that the current through it may be reversed in direction though that in the rest of the circuit and therefore through  $M_s$  is still unidirectional.

With  $R$  large, close  $S$ , and obtain say  $\frac{1}{2}$  full scale deflection on  $M$ , noting that on  $M_s$  which must be constant; now reverse current in  $M$  and again note its value for the same one as before on  $M_s$ . Next re-reverse and note it again.

(11) Repeat this operation for about 5 scale readings on  $M$  up to the maximum at roughly equal intervals.

N.B.—This test of course only applies to direct current instruments. Tabulate as follows—

Standard instrument used: Type . . . No . . . Maker . . . Constant = . . .  
Instrument tested: Type . . . No . . . Maker . . .

E. Effect of Current Reversal.				F. Heating Effect.		
Reading of				Time of Heating Hours	Reading on	
$M_s$ (constant).	$M$ direction of current.				$M_s$	$M$
	←	→	Reversed ←			

## (12) ERROR IN VOLTMETERS (ONLY) DUE TO HEATING OF COILS BY PASSAGE OF CURRENT. (F.)

Close  $S$ , and adjust  $R$  to obtain about  $\frac{1}{2}$  scale reading on  $M$ , note the corresponding reading on  $M_s$  which must be an electrostatic voltmeter. Maintain  $M_s$  constant for, say, quarter of an hour and again read  $M$ .

(13) Repeat 12 for a full scale reading on  $M$ , and tabulate as before.

N.B.—The error in voltmeters due to change in the temperature of the room is readily calculable when the latter is obtained by a thermometer.

(14) Plot the following curves for tests—

B. Having readings on  $M$  as ordinates, and  $M_r$  as abscissae for both ascending and descending curves.

C. Having readings on  $M$  as ordinates and frequency in  $\omega$  per sec. as abscissae.

D. Having readings on  $M$  as ordinates and frequency in  $\omega$  per sec. as abscissae.

**Inferences.**—State very clearly and concisely what you can infer from the results of your observations.

#### (14) Calibration of a Wattmeter by Comparison with a Kelvin Composite Balance used as a Wattmeter.

**Introduction.**—The following is a convenient method of calibrating a Wattmeter by means of direct currents, using a Kelvin composite balance as the standard Wattmeter with which to compare the one to be tested. The construction of the balance is detailed on p. 554, where the mode of using it as a Wattmeter is also given, and it will merely suffice to say here that it is used very similarly to the Hekto-amperometer, the only difference being that as a Wattmeter, the fine wire movable coils (only) are placed in series with an extra anti-inductive resistance across the mains supplying the power measured by both Wattmeters. It may here be noted that it is not necessary for the current through the thick winding and the pressure across the thin coils to be developed by one and the same source. For since the Wattmeter deflection is  $\propto$  to the products of the currents flowing through the two coils, clearly these may come from two totally different sources. In fact it is distinctly preferable to have them separate when possible, for then the variations of the main current will not affect the constancy of the pressure on the fine coils.

This same test serves to determine the "constant" ( $K_w$ , say) of the Wattmeter, or in other words the number by which the scale reading must be multiplied so as to obtain the power in Watts.

The following reasoning will no doubt render this clearer.

Assuming the general principle and construction of, suppose, a Siemens Wattmeter to be understood. Let  $C$  and  $c$  = the currents flowing through the fixed thick- and movable thin-wire coils respectively when a deflection of the torsion head and its pointer on the scale is  $D'$  or divisions. Then the force acting between the coils is  $\propto C \times c$ , but  $(c) \propto$  to the pressure  $V$  at the terminals. Hence the deflecting couple acting between the coils  $\propto C \times V \propto$  Watts. Now when the index is brought back to 0 again by turning the torsion head, thereby twisting up the spring and introducing the control, we have—torsion of spring  $\propto$  Watts  $\propto CV$ ; but the force of torsion is  $\propto$  to angle of torsion of such a spring,

$$\therefore D \propto CV$$

or  $KD = CV =$  Watts measured and causing a deflection  $D$ , where  $K$  is the "constant" of the Wattmeter tested. It may be found that  $K$  is not perfectly constant throughout the whole scale. In this case the Watts should be obtained from a calibration curve rather than by the product  $KD$ .

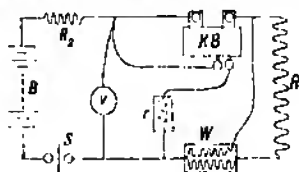


FIG. 15.

**Apparatus.**—Kelvin composite balance ( $K.B.$ ) (p. 554), with its anti-inductive resistance  $r$  (p. 553); switch  $S$ ; variable power-absorbing resistance  $R$  (p. 686); accurate voltmeter  $V$  (preferably electrostatic); main current battery  $B$ ; Wattmeter ( $W$ ) to be calibrated; (pressure battery  $b$  and adjustable resistance  $R_1$  if available (Fig. 16)); adjusting rheostat  $R_2$  (p. 597).

**Observations.**—(1) Connect up either as in Fig. 15 or 16, and in the present test assume the latter for actual experiment, and make quite certain that the connections are as indicated in Fig. 16.

(2) Carefully level the instruments that require it, adjusting their pointers to zero, and if  $W$  has a suspended coil see that this is quite free to move.

**Note.**—Care should be taken to run the “leading in” and “out” wires carrying the main current to  $W$ , and in the rest of the circuit close together or twisted in order that the currents flowing in them shall exert no magnetic influence on the instruments.

(3) Turn the switch on the balance to “Watts” so as to place the movable fine wire coils across the small terminals. Observe whether ( $r$ ) is numbered the same as, and therefore belongs to the balance in use, and make quite certain that the correct resistance is being used in ( $r$ ) (p. 523).

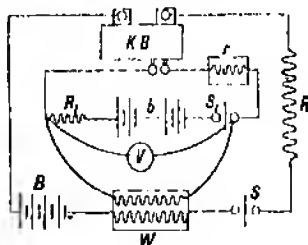


FIG. 10.

(4) Adjust the balance and its sensibility by using the proper weights as given in the table of constants (p. 558), so that the maximum Watts to be measured on  $W$  would give, as nearly as possible, a full scale reading on  $KB$ .

(5) With  $R_1$  fairly large, close  $S_1$  and adjust the voltage as read off on  $V$  to the desired amount by altering  $R_1$ , and then maintain this voltage constant, observing that it is so before taking every reading.

(6)  $R$  being fairly large, close  $S$ , and alter  $R$  so as to obtain about  $\frac{1}{3}$ th of the maximum scale reading on  $W$ . Note simultaneously the reading on  $V$  and position ( $d$ ) of the slider of  $KB$ .

(7) Repeat 6 for some ten different deflections on  $V$  (by varying  $R$ ) rising by about equal increments to the maximum, the pressure remaining constant all the time.

(8) Repeat obs. 7 for a similar set of decreasing readings on  $W$ , and tabulate your results as follows—



NAME . . . . . DATE . . . . .  
 Compound Balance No. . . . . Constants of  $K_p$  . . . . . Temperature . . . °C  
 Wattmeter Serial No. . . . . Maker . . . . . Range . . . . . Meter's Constant . . .

Meter Reading • $d$	True Watts $K_p d$	Reading on $W$		Constant $K_p = \frac{K_{std} d}{\text{mean } D}$	% Error of Wattmeter	Mean % Error
		Ascending $D$	Descending $D$			

(9) Plot a "calibration" curve for the Wattmeter tested having values of  $D$  as ordinates and true Watts as abscissas.

**Inferences.**—What can be inferred from the results of your test? Are Wattmeters subject to any sources of error, and if so, how can they be minimized or got rid of?

#### (15) Calibration of a Wattmeter by Comparison with a Standard Ammeter and Voltmeter.

**Introduction.**—The following method of calibration by direct currents entails the use of an accurately calibrated standard ammeter and standard voltmeter. These may be either Kelvin balances or ordinary instruments which have recently been carefully compared with accurate standards, and a record of the calibration curves of which are obtainable.

It should be remembered that the constant of a Wattmeter obtained with direct currents will only be true for alternating currents providing the self-induction of the fine wire moving coil or its circuit is practically zero or very nearly so. In other words, the instrument must contain no iron and also be very nearly "non-inductive." This is a matter of great importance, for Wattmeters are in most cases only required to measure power in alternating current circuits.

**Apparatus.**—Standard ammeter ( $A$ ) and voltmeter ( $V$ ); Wattmeter ( $W$ ) to be calibrated with its anti-inductive resistance ( $r$ ) if there is one; battery of secondary cells  $B$ ; switch  $S$ ; suitable resistance  $R$  for absorbing power (p. 606), which must be non-inductive if alternating currents are employed; carbon rheostat ( $RA$ ) (p. 587).

**Observations.**—(1) Connect up as shown. Carefully level all the instruments, adjusting their pointers to zero, and see that

the swing coil of the Wattmeter is quite free to move. Care should be taken to run the "leading in" and "out" wires carrying the main current to the Wattmeter, also together or

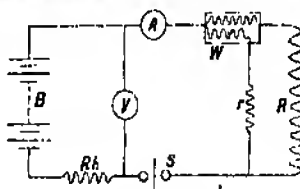


FIG. 17.

twisted. Also the main wires of the rest of the circuit close together in order that the current flowing in them shall exert magnetic influence on any of the instruments.

(2)  $R$  being at its maximum value, close  $S$ , and adjust  $R$  so as to obtain about  $\frac{1}{10}$ th of the full load current through  $W$ , the pressure being maintained at standard voltage by varying the carbon rheostat ( $Rk$ ). Note the readings of all the instruments.

(3) Repeat 2 for about ten different readings on  $W$  rising by about equal increments to the maximum current allowable, and calculate for each the percentage error of the Wattmeter and the mean. Tabulate as follows—

NAME . . . . . DATE . . . . .  
Non-inductive Wattmeter: No. . . . . Maker . . . . . Temperature = . . . °C.

True Volts. $V$ .	True Amperes $A$ .	True Watts $W = AV$ .	Wattmeter Reading. $D$ .	Wattmeter Constant $K = \frac{W}{D}$ .	Percentage Error of Wattmeter	Mean Error.

(4) Plot a curve having values of ( $W$ ) as abscissae and the corresponding Wattmeter readings ( $D$ ) as ordinates.

### (16) Calibration of a Wattmeter with Alternating Currents. (Three-Voltmeter Method.)

**Introduction.**—Wattmeters form a class of measuring instrument the chief application of which consists in measuring

*accurately* the power taken up in alternating current circuits. The *great* value of a Wattmeter in such measurements practically disappears with direct currents as the individual factors of power, namely "volts" and "amperes," are usually here required, and in addition the product of the two can easily be obtained and at once gives the "true power." With alternating currents, however, this last remark is not true, and herein lies the great value of the properly constructed Wattmeter, in that it measures the true power in such a circuit. For it to be capable of doing this, however, it must be carefully constructed, and there must be *no iron* and preferably no other metal work near the coils. Wattmeters when used on alternating current circuits are liable to the following sources of error: (a) owing to the fine wire coil possessing some self-induction and consequently impedance, the current in it is not able to rise to the same maximum strength which it would do for a direct P.D. of similar magnitude; (b) this impedance causes a lag in phase of the current in the fine wire coil behind the P.D. across which it is placed.

(c) A third source of error common also to all voltmeters, and occurring both with direct and alternating currents, is that due to the alteration of the resistance of the fine wire coil due to change of temperature, and which can be minimized in the manner described later on. From the preceding remarks it will therefore be evident that when a so-called "Non-inductive Wattmeter" is calibrated with direct currents (which is usually the case) its "*constant*" so obtained will *not* be *correct* for alternating currents. The instrument will also read differently for variation of the "frequency" of the current even though the actual power being measured remains the same. Thus a Wattmeter may with advantage be calibrated with alternating currents on a circuit having the same "constants," namely voltage, frequency and "wave form," etc., as that in which it is eventually desired to measure the power. The calibration can be performed by what is commonly known as the 3-voltmeter method of measuring power in alternating current inductive circuits, and by it the "*true power*" may be obtained with almost any degree of accuracy desired by using an accurately calibrated voltmeter and by repeating the observation two or three times, noting the *mean*. It has the advantage that only

one alternating current voltmeter is required, though three similar ones may be used if available.

**Apparatus.**—Alterator *D* and its exciting circuit (not shown)

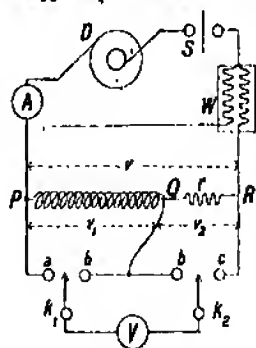


FIG. 18.

under rheostatic control or other convenient source of alternating current supply; inductive portion *PQ* of the circuit in series with a strictly non-inductive portion *QR*; two 2-way keys *k*<sub>1</sub>, *k*<sub>2</sub> (p. 587); Char-dew or low-reading electrostatic voltmeter *V* accurately calibrated; main switch *S*; Wattmeter *W* to be calibrated; alternating current ammeter to indicate the current merely for reference only.

**Note.**—The resistances of *PQ* and *QR* should both be

fairly small compared with that of the voltmeter *V*.

**Observations.**—(1) Connect up as in Fig. 18, and adjust the pointers of all the instruments to zero, levelling such as need it. See that all lubricators in use feed properly, and then start *D*.

(2) Adjust the speed of *D* so as to obtain the desired "frequency," say 100 — per sec., at the same time varying the excitation to get the proper voltage, suppose 100 volts across *PR*. Adjust the resistance of *PR* so as to pass about  $\frac{1}{10}$ th of the full load current (necessary to give a full scale reading on *W*) through *W*. Then the speed and voltage being constant, note the reading on *A*, *W*, and in quick succession the voltages *V*<sub>1</sub>, *V*<sub>2</sub> and *V* across *PR*, *PQ*, and *QR* respectively by moving *k*<sub>1</sub> and *k*<sub>2</sub> simultaneously.

(3) Repeat 2 for about ten different currents rising by about equal increments to the maximum allowable.

(4) Calculate the power absorbed in *PR* from the relation

$$W_1 = \frac{1}{2r} (V^2 - V_1^2 + V_2^2) \text{ Watts,}$$

where *r* is the ohmic resistance of *QR*.

If *r* is unknown or liable to be altered by the heating effect

of the current, its value  $r = \frac{V_2}{A}$  may be substituted in the above relation. If the current and voltage are sine functions,

$$\cos \theta = \frac{V^2 - V_1^2 - V_2^2}{2V_1V_2}$$

(5) Repeat 2-4 for a different frequency, say 60 per sec., to see whether the Wattmeter "constant" ( $K$ ) alters, and tabulate your results as follows—

NAME . . . . .				DATE . . . . .			
Wattmeter tested: No. . . . .				Range . . . . .			
Maker . . . . .				Temperature . . . . .			
Speed r.p.m.	Power Factor $W_1/A$	Angle of Lag or $V_2/A$	Current in Amps $A$	Volts, $V_1$	Power, Apparent $W_1$	Wattmeter, Reading $d$	Error, Constant $K = W_1/d$

**Note.**—Errors made in measuring the voltages  $V$ ,  $V_1$  and  $V_2$  or in the graduation of the voltmeter scale will have least effect on the results when  $V_1 = V_2$ . If the formula in 4 is used with the substituted value of ( $r$ ), this latter may consist of glow lamps, as the resistance may vary with the different mean current strengths.

(6) Plot a calibration curve for the Wattmeter tested, having values of deflection  $d$  as ordinates and true power  $W_1$  as abscissae.

**Inference.**—Prove the formula given in 4 and state any assumption made in obtaining it. What inferences can you draw from the results of your test and explain why the resistance of the voltmeter  $V$  should be large compared with either  $PQ$  or  $QR$ .

### (17) Calibration of a High Tension Wattmeter. (By Ohm's Law, using an auxiliary transformer.)

**Introduction.**—It is not always possible in actual practice and testing work to avoid the use of a Wattmeter on a high tension circuit, as for instance would be the case in measuring the efficiency of a high tension transformer run off the terminals of a high tension alternator. The Wattmeter in such a case should be a specially arranged one for the following reasons—

(1) Owing to the high pressure in the fine wire moving coil circuit, an extremely high *non-inductive* resistance, capable of standing the full pressure across its terminals, would otherwise have to be put in series with the fine wire swing coil if an ordinary Wattmeter was employed.

(2) Owing to the difficulty in obtaining the above resistance.

(3) The risk entailed in handling such an instrument, and of the breakdown of the insulation of the whole arrangement under the high pressure.

The best arrangement of a high tension Wattmeter, and which gets over these difficulties, is that shown symbolically in Fig. 19, together with the connections for its calibration.

The Wattmeter *W* consists of an ordinary Siemens electro-

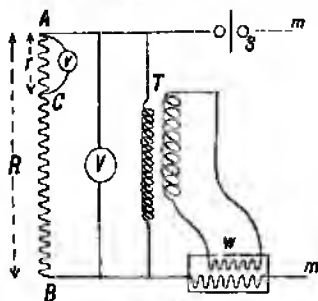


FIG. 19.

dynamometer; the mercury cups, forming the terminals of the swing coil, are connected to a separate pair of terminals by the side of the other pair forming those of the fixed coil. There is thus no electrical connection between the fixed and moving coils. These latter are connected to the low pressure

coil of a small auxiliary transformer *T*. The high tension side of *T* is placed across the high pressure mains (*h.t.m.*), hence the moving coil of *W* passes a current which depends on the E.M.F. of *h.t.m.*, and at the same time there is no fear from a breakdown of insulation since both coils of *W* are passing ordinary currents. The actual current which *T* sends through the swing coil of *W* may be as small as convenient.

**Apparatus.**—High tension Wattmeter *W* to be calibrated arranged as mentioned above, with its fixed and movable coils separate. Small auxiliary (H.T.) transformer *T*; high and low tension electrostatic voltmeters *V* and *v* respectively; strictly non-inductive resistance *ACB* capable of being placed

across the (H.T.) mains *m.m.*, and of carrying enough current at that pressure to enable a considerable scale deflection to be obtained on *W*. A part *AC* of the whole resistance *AB* should have such a value (*r*) and be of such a carrying capacity as not to be heated and changed by the current through *ACB* and as will have a P.D. across its terminals capable of being read on *v*.

**Note.**—As a precaution, india-rubber gloves must be worn, and an india-rubber mat provided to stand on.

**Observation.**—(1) Connect up as in Fig. 19, and adjust the instruments carefully to zero.

(2) Close switch (*S*) and adjust *V* to read the desired amount which *W* has to deal with on future occasions. Note the readings of *V*, *r*, and *W*, and tabulate as follows—

Name . . .				Date . . .			
Wattmeter tested: No. . . .				Maker . . .	Range . . .	Temperature . . .	
Non-inductive Resistance		Voltage		Current through <i>ACB</i> $A = \frac{V}{r}$	True mean Watts in <i>ACB</i> $W_1 = VA$	Reading on Wattmeter $W_2$	Constant of Wattmeter $W_1/d_2 = K$
R.	r.	V.	v.				

**Inferences.**—Is the method liable to any sources of error? and if so, state them.

### (18) Calibration of an Electricity Meter (on Constant Supply).

**Introduction.**—An electricity meter, which performs the same kind of office to a consumer of electrical energy that a gas-meter does to one using ordinary gas, is an electrical instrument that requires carefully calibrating or standardizing at some time or another. There are a great number of different forms of electricity meters, but they all come under one or other of four main classes, namely—ELECTROLYTIC, THERMAL, MOTOR, CLOCKS AFFECTED. It is not, however, our intention to dilate on those further as their theory and description comes under the scope of the ordinary textbook, but there are some points in general which may be remarked. Practically all meters measure one or other of two things, namely,

across the (H.T.) mains *m.m.*, and of carrying enough current at that pressure to enable a considerable scale deflection to be obtained on *W*. A part *AC* of the whole resistance *AB* should have such a value (*r*) and be of such a carrying capacity as not to be heated and changed by the current through *ACB* and as will have a P.D. across its terminals capable of being read on *V*.

**Note.**—As a precaution, india-rubber gloves must be worn, and an india-rubber mat provided to stand on.

**Observation.**—(1) Connect up as in Fig. 19, and adjust the instruments carefully to zero.

(2) Close switch (*S*) and adjust *V* to read the desired amount which *W* has to deal with on future occasions. Note the readings of *V*, *r*, and *W*, and tabulate as follows—

NAME . . .				DATE . . .		
Wattmeter tested: No. . . .		Maker . . .		Range . . .		Temperature . . .
Non-inductive Resistances		Voltages		Current through <i>ACB</i>	True mean Watts in <i>ACB</i>	Reading on Wattmeter
<i>R</i> .	<i>r</i> .	<i>V</i>	<i>V<sub>r</sub></i>	$A = \frac{V}{r}$	$W_1 = V A$	<i>d<sub>w</sub></i>

**Inferences.**—Is the method liable to any sources of error? and if so, state them.

### (18) Calibration of an Electricity Meter (on Constant Supply).

**Introduction.**—An electricity meter, which performs the same kind of office to a consumer of electrical energy that a gas-meter does to one using ordinary gas, is an electrical instrument that requires carefully calibrating or standardizing at some time or another. There are a great number of different forms of electricity meters, but they all come under one or other of four main classes, namely—ELECTROLYTIC, THERMAL, MOTOR, CLOCKS AFFECTED. It is not, however, our intention to dilate on these further as their theory and description comes under the scope of the ordinary textbook, but there are some points in general which may be remarked. Practically all meters measure one or other of two things, namely,



(a) Ampere-hours, when they are called *quantity* or *Coulomb-meters*, (b) Watt-hours, when they are termed *Energy* or *Joule-meters*. In most cases, though by no means all, meters are graduated and read directly in the official "Board of Trade Unit" (1000 Watt-hours). It must not, however, be supposed that because a meter reads Board of Trade units on its dials it is a true energy meter in the real sense of the word, i.e. a meter containing a current and pressure coil acting on one another in a suitable manner, for if the pressure is pre-assumed and taken as being constant it is an easy matter to graduate and calibrate the dial of a Coulomb meter to read directly in B.O.T. units. This it may be remarked is generally done now.

**Apparatus.**—Accurately calibrated ammeter  $A$ , and voltmeter  $V$  secondary battery  $B$ , or steady source of supply; switch  $S$ ; power

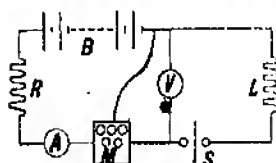


FIG. 20.

absorbing resistance  $L$ , or bank of lamps (p. 598); rheostat  $R$  (p. 597), which might be required for adjusting the pressure on the mains; meter  $M$  to be tested. When possible, it is best and most economical in power used, to employ two

distinct circuits, one giving the necessary voltage for the fine wire coil of  $M$ , if there is one, the other the necessary current through the current circuit of  $M$ . These two sources must be secondary batteries if possible so as to be quite constant.

**Note.**—If the meter to be tested is an alternating current one then  $A$  and  $V$  should be alternating current instruments, such as a Siemens electro-dynamometer and electrostatic voltmeter respectively, or the author's instruments.  $R$  also should be non inductive, and  $L$  may preferably consist of a bank of lamps (p. 698) or other non-inductive resistance. If an accurately calibrated non-inductive Wattmeter is available, then the true power given to  $M$  can at once be obtained irrespective of the nature of  $R$  and  $L$  and also without using  $A$ . In such cases the meter should be tested at different frequencies and on inductive loads.

**Observations.**—(1) Fix up the meter in a position as nearly vertical as possible and connect it in circuit so as to register the

quantity (amp.-hours) or energy (Watt-hours) as the case may be, given to  $L$ .

(2) If the meter is intended for use on 100 or 200 volt circuits, close  $S$  and vary  $L$  so as to absorb the full load current of the meter, and adjust  $R$  so that  $V$  reads the required voltage.

(3) Open  $S$  and take the dial readings of the meter.

(4) At a known tabulated instant, switch on, and keep the current ( $A$ ) and pressure ( $V$ ) constant for about  $\frac{1}{2}$  hour by altering  $R$  and  $L$  if necessary. Then switch off at a noted instant and take the dial readings again.

(5) Repeat 2, 3, and 4 for  $\frac{3}{4}$ ,  $\frac{1}{2}$ ,  $\frac{1}{4}$  and  $\frac{1}{10}$  full load currents through the meter, and tabulate as follows—

NAME . . .		MAKER . . .		DATE . . .			
Meter tested: Type . . .		Voltage (if any) . . .		No. . .			
Amps. (full load) . . .		Dial reading in . . .					
Meter reading		Amount Registered $Q_2 - Q_1$	Amps $A$	Volts $V$	Time $T$ (Hours)	Consumption or Watt-hours	Error of Meter
Start $Q_1$	End $Q_2$						

**Inferences.**—State the chief conditions which a meter of the above type should fulfil.

### (19) Complete Test of an Electricity Meter.

**Introduction.**—In order to completely test an electricity meter in the way that would be advisable with any new type of instrument, three or four additional tests other than the preceding one should be carried out and are as follows:—

(a) *Starting power of the Meter.*—Obtained by carefully measuring the *least* current or Watts that will just cause the meter to start. It is obvious that such should not exceed the amount used up in the smallest lamp employed.

(b) *Effect of external Magnetism.*—Which can be investigated by sending a steady current or number of Watts through the meter according to what it measures, and then bringing a strong magnet into a number of different positions about the outside of the meter. The record of the instrument taken over a sufficient

period for each position of the external magnet should remain unaltered.

(c) *Power absorbed in the Shunt-coil.*—Some motors possess a fine shunt coil of considerable resistance for the purpose of providing the instrument with a sufficient magnetic field to enable it to start with a very small current. The amount of power absorbed in this coil, if there is one, should be carefully measured and the cost of it per annum calculated on the basis of say 3d. to 4d. per B.T.U. if the supplier pays for it as he should. It should also be observed whether this coil is across the lamp or supply side of the meter in order to see if the consumer or supplier pays for the power so wasted, for in the aggregate the cost of this may amount to a considerable sum in the course of the year.

(d) *Gradual deterioration of working parts.*—This is most important, but can only be determined by a "time test" extending over a considerable period amounting to months.

Thus to furnish a true and accurate report on an electricity meter, investigations (a—d) should be undertaken, and in addition the test immediately preceding them.

## (20) Measurement of a Resistance heated by an Electric Current.

**Introduction.**—When a resistance is heated by the passage of a current its value so heated may or may not be very different from that when it is cold. Thus, for example, a resistance composed of the alloys Manganin or Eureka, etc., would alter its resistance very little for considerable changes of temperature; whereas if made of carbon, the specific resistance of which diminishes rapidly as the temperature rises, the resistance would be very different when hot to what it would be while cold. In practice, however, one of two conditions may occur in connection with heated resistances, namely, (1) The type and form may be such that the temperature does not fall very quickly immediately the current is cut off, thus enabling time measurements of resistance to be taken with, say, a Wheatstone Bridge or other suitable means, and the resistance *hot*, at the moment of breaking the current, to be obtained graphically by plotting the results; owing,

however, to the difficulty of taking rapid time measurements of resistance and the introduction of other errors we shall not consider this method further. (2) The type of resistance may be such that the temperature falls very rapidly and far too quickly to enable any measurements, as in 1 above, to be taken. Such is the case with the filament of an electric incandescent lamp, and in order to obtain its resistance (warm), accurately, *during the passage of a current*, and which is absolutely necessary, another method has to be employed other than that of the Wheatstone Bridge, etc.

Though the results of the present test will disclose the fact, it may be mentioned here that the filament resistance of an electric glow-lamp when burning normally is very different from that when cold. Thus this latter, which can best be obtained by the Wheatstone Bridge, would not in any way represent the true resistance while the filament is under working conditions.

We will assume that the resistance in question is of the nature of an electric glow-lamp and therefore cools far too rapidly to allow of the employment of the first method mentioned. For a concrete case suppose that the resistance of the filament of an electric incandescent lamp is required at different luminosities, i. e. when different currents are passing through it. This resistance will diminish as the current increases, or as the temperature increases, owing to the specific resistance of carbon diminishing as the temperature rises. This property of carbon, in having a *negative* coefficient of variation of resistance with temperature, should be remembered as compared to the same property of all the metals and nearly all the alloys, of which "*Manganin*" may be cited as an exception in having a negative coefficient. The present method is a direct application of Ohm's Law, and consists in measuring the current through the lamp and the voltage across its terminals. There are, however, some precautions which have to be adopted in order to obtain the *true voltage and current*, and these we may now point out in connection with the two arrangements possible with this method. In each of the cases I, and II, (*V*) represents the voltmeter, (*A*) the ammeter, and *R* the glow-lamp or other resistance to be measured while hot. The rest of the main circuit is omitted for simplicity, but may comprise a suitable secondary battery and a rheostat for varying the current

through  $E$ . In *Case I*, the voltmeter  $V$  is connected directly to the terminals of  $R$ , hence the ammeter  $A$  will measure the sum of

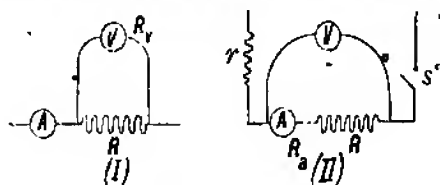


FIG. 21.

the currents through  $V$  and  $R$  together. But the method requires the actual current through  $R$  only, which is found as follows—

Let  $R_v$  = the true resistance of the voltmeter in ohms.

Then  $\frac{V}{R_v}$  = the true current flowing through it in amperes,

whence the actual current through  $R$  =  $A - \frac{V}{R_v}$  amperes and the

$$\text{resistance of } R \text{ (hot)} = \frac{V}{A - \frac{V}{R_v}} \text{ ohms.}$$

To see the magnitude of the error caused by neglecting the correction for the voltmeter current, suppose  $V=100$  volts,  $R_v=10,000$  ohms and  $A$  reads 0.61 amperes. Then without correction:

$$R \text{ (hot)} = \frac{V}{A} = \frac{100}{0.61} = 163.93 \text{ ohms, and with correction } R \text{ (hot)}$$

$$= \frac{V}{A - \frac{V}{R_v}} = \frac{100}{0.61 - \frac{100}{10000}} = \frac{100}{0.60} = 166.66 \text{ ohms.}$$

In other words the error made in the resistance, neglecting the correction, = 1.64%. It should, however, be remembered that the average commercial voltmeter has a resistance much less than 10,000 ohms, and hence the above error would be much greater when using such. If  $R_v = \text{Infinity}$  then no correction is necessary; for, the resistance of  $R$  (hot) then =

$$\frac{V}{A - \frac{V}{R_v}} = \frac{V}{A - \frac{V}{\infty}} = \frac{V}{A} = \frac{V}{A}$$

ohms or the voltmeter passes no current.

Such is the case with any electrostatic instrument such as the Kelvin multicellular voltmeter, the resistance of which is practically infinite. It is therefore a good one to use for the purpose.

In *Case II.* the voltmeter is connected across the ammeter and resistance combined, and it will therefore measure the *sum* of the voltages across  $R$  and  $A$ . But the actual voltage across  $R$  only, is required by the method, and this is obtained as follows—

Let  $R_A$  = the true resistance of the ammeter in ohms.

Then  $AR_A$  = the true voltage across the ammeter terminals, whence, the *actual voltage across  $R$*  =  $V - AR_A$  volts and the

resistance of  $R$  (hot) =  $\frac{V - AR_A}{A}$  ohms.

To see the error caused by neglecting the voltage lost in the ammeter. Let  $V$  read 100 volts and  $A$  read 0.6 amperes, assume  $R_A = 0.1$  ohm, which is about the value for an instrument reading such small currents. Then we have

$$\text{without correction } R \text{ (hot)} = \frac{V}{A} = \frac{100}{0.6} = 166.66 \text{ ohms.}$$

$$\text{and with correction } R \text{ (hot)} = \frac{V - AR_A}{A} = \frac{100 - 0.06}{0.6} = \frac{99.94}{0.6} = 166.57.$$

Or the error made in not allowing for the loss of voltage in  $A$  is 0.054%. Thus, although the resistance of  $V$  can easily be measured on a Wheatstone Bridge and that of  $A$  either by the bridge or by the "fall of Potential" method (*vide* p. 84), when these cannot be readily obtained, we see that *Case II.* will give the best results and the freest of the two from error by neglecting any corrections.

**Apparatus.**—Accurate ammeter  $A$  and voltmeter  $V$ ; the resistance  $R$  or glow-lamp to be measured while hot. The rest of the main circuit, if this is not already set up, comprising secondary battery, rheostat  $r$ , switch  $s$ , etc. Arrangements should be at hand for measuring the resistance of  $V$  and  $A$ , viz.—P. O. Bridge, galvanometer, Leclanché cell and standard known 0.1 ohm resistance, etc.

**Observations.**—(1) Connect up as in *Case II.* Fig. 21, and adjust the pointers of  $V$  and  $A$  to zero.

(2) Measure the resistance of the ammeter, voltmeter, and lamp (cold) by suitable means.

(3) Take a series of simultaneous readings on  $A$  and  $V$  for different voltages, rising by intervals of 10% from 0 to within about 5% of the normal, and then by steps of 1% to 5% above normal voltage.

(4) Repeat (3) above, using a metal filament lamp instead of the carbon one, and tabulate thus—

Name . . . . . Date . . . . .  
 Nature of Resistance tested . . . . . Resistance Cold = . . . Ohms.  
 Ammeter "  $R_A$  = . . . " "  
 Voltmeter "  $R_V$  = . . . " "

Reading on Voltmeter.	True Volts ( $V$ ) across Lamp.	Current through Lamp ( $A$ ) Amperes.	Resistance (hot) $R = \frac{V}{A}$ Ohms.	% increase or decrease of resist. when hot.

(5) Plot curves for each lamp having values of lamp resistance as ordinates and corresponding currents through it and voltages across it, both as abscissae.

## (21) Measurement of the Efficiency and Candle Power of Electric Glow Lamps.

**Introduction.**—At the present day, when new forms of electric incandescent lamps are frequently making their appearance before the general public, or otherwise, it becomes of scientific interest and often of practical importance to thoroughly test the advantages claimed for these particular forms, and to discover their disadvantages. Amongst others, the chief investigations should be—

(a) The efficiency at and about the normal or rated voltage, stamped on the lamp by the makers. This is reckoned in "Watts per candle" for commercial purposes, though it should more correctly be termed its "in-efficiency." The number of "candles per Watt" more properly denotes the efficiency of a glow lamp as a light emitting source.

(b) The candle power (U.P.) at the rated voltage and in a given direction.

(c) At what efficiency, the total cost of operating this particular form of lamp, is a minimum.

These three investigations are of considerable moment to the user of such lamps, and the results practically decide whether his annual expense of electric lighting, using such a form of lamp, would be greater or less than with the present lamps in use. It

may probably be the case that it is impossible to do anything with the investigation marked ( $\gamma$ ), owing to there being insufficient data to hand, the data required being (1) the cost of energy supplied, (2) the cost of lamp, (3) rate of variation of the life with Watts per candle, which is the most difficult item of the

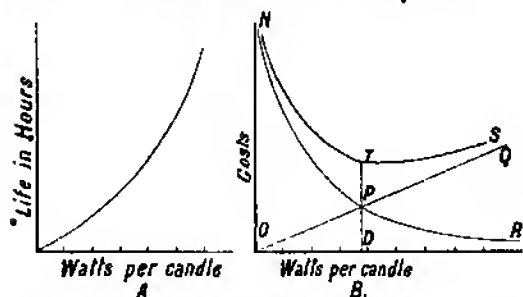


FIG. 22.

three to obtain. For purposes of discussion, however, as this particular question is of considerable interest, we will assume that very carefully-made tests give the relation between the life in hours of the lamp and the efficiency, or Watts per candle used, as shown in curve *A*, Fig. 22. Then on plotting curves *B* of the same fig., the cost of lamp renewals per hour will give us the curve *NPR*, and the cost of energy per candle-hour will give us the straight line *OPQ*. Summing the ordinates of the two curves, we get the third curve *NTS* convex to the abscissa and representing the total cost of the only two sources of expenditure, namely, cost of lamps and cost of energy. If now an ordinate through the lowest point *T* of this third curve cuts the abscissa in the point *D*, then *OD* (in this case 3·8) gives the efficiency, or Watts per candle, at which the total cost of operating this form of lamp is a minimum for the particular electrical supply taken.

- The two first-named investigations ( $\alpha$  and  $\beta$ ) are contained in the following relations, which must be determined, viz.—
- (4) efficiency (Watts per candle), (5) resistance of filament, and
  - (6) the cost per candle-hour for energy with efficiency.



The candle power may be obtained by employing some convenient form of photometer, such as any one of those described on p. 589. We shall, however, here assume the use of a Bunsen grease-spot photometer, the carriage of which slides along an ordinary straight graduated bank or bench containing the standard of light at one end and the glow lamp to be tested at the other. If now  $C$  = the C.P. of the standard of light, and ( $d$ ) its distance from the grease spot when "balance," in the manner to be described later, is obtained, also if  $D$  = distance between standard and lamp to be tested, then the C.P. of this lamp is

$$K = C \frac{(D-d)^2}{d^2}.$$

Now to facilitate working out the results of the tests, a calibration curve for the photometer bench may be drawn from calculations in which values of ( $d$ ) are abscissæ, and the corresponding ones for  $\frac{(D-d)^2}{d^2}$  as ordinates. Thus the ordinates of this curve  $\times$  by the C.P. of the standard will give directly the C.P. of the lamp to be tested corresponding to the particular distance ( $d$ ). The values of  $\left(\frac{D-d}{d}\right)^2$  for various values of  $d$  when  $D=2, 3, 4, 5$  and 6 metres, are given in the Table, p. 651, and they will be found to save a great deal of time in working out the results of photometric tests in general. Intermediate values not given in the table can best be obtained from the curve plotted between the numbers pertaining to the value of  $D$  used in the test and the values of  $\left(\frac{D-d}{d}\right)^2$ .

Referring to the above formula for calculating the unknown C.P., we see that any error made in reading the true position of the carriage carrying the "grease spot" or other balancing device will have minimum effect when  $K = C$  or  $d = (D-d)$ , i. e. when this carriage is at the midway position between the two sources of light. The same kind of thing occurs in the case of measurements of resistance by the "Metre Bridge." To fulfil, however, the relation just mentioned, it will in most cases be necessary to employ a subsidiary or intermediate standard of light, such as a good electric glow lamp, which has itself been very carefully standardized by reference to an ordinary smaller standard.

Considerable difficulty may sometimes be experienced in balancing on the photometer with the naked eye when different sources of light are being compared owing to the difference in colour of the lights. In such cases it is of advantage to observe the "sight-box" containing the Bunsen grease spot or other arrangement through coloured glass when balancing; that known commercially as "signal red" and "green" being the best for the purpose, and two pieces should be chosen, so that on looking through the two together in bright daylight next to no light passes through them. Thus on balancing the sight-box by observing through each separately, the mean of the readings will afford a correction to a certain extent for any difference in colour of the two sources of light.

The principal object gained in using coloured glasses is that the eye then observes a less bright surface, and is consequently better able to gauge its illumination relatively to the surrounding surface. It is a fact that when the eye looks at a very bright surface, the pupil of the eye partially contracts, thus causing the effect of temporary partial blindness, hence the use of coloured glass to prevent this.

It should be carefully remembered that if the resistance of the voltmeter, which measures the pressure, is not very high compared with that of the lamp (say exceeding 100 times), and the ammeter resistance not very low compared with that of the lamp ( seldom the case), then corrections must be applied to one or other of these instrument readings, in order to obtain either the true voltage on the lamp or true amperes through it. For such see test on p. 48.

**Apparatus.**—Low reading ammeter *A* with long open scale (p. 559); high resistance voltmeter *V*; adjustable fairly high resistance *R* (Fig. 272); secondary battery and photometer bench *DD* complete, containing "Methven screen" 2 C.P. standard (*C*) of light (p. 595), or Fleming standard glow lamp; glow lamp *G* to be tested; and "sight-box" *B* containing a Bunsen grease spot (p. 593), or Flicker photometer head; switch *S*.

**N.B.**—For particulars on the adjustment and use of the Methven standard, see Appendix, p. 595. The lamp *G* to be tested may be run as low as will give measurable luminosity, but not higher than 5% above its normal voltage.

**Observations.**—(1) *Fix*, in a manner most convenient for calculation, *the distance  $D$*  between standard and lamp to be tested (500 cms. say), and adjust the standard to the certified standard value of C.P.

If a standard glow lamp is used instead of  $C$  connect it to a constant voltage supply through an exactly similar circuit to that shown for  $C$ , but without an ammeter ( $A$ ).

(2) Connect up the glow lamp as indicated in Fig. 23, and adjust the pointers of  $V$  and  $A$  to zero, levelling the instruments carefully if necessary.

(3) Measure the resistance of the lamp filament while cold by means of the Wheatstone Bridge, and note its value.

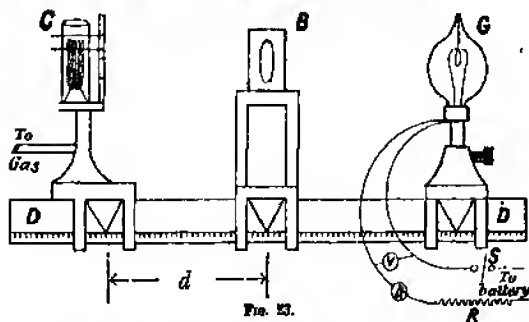


FIG. 23.

(4) Close  $S$  and adjust  $R$ , so as to obtain just measurable luminosity on  $G$ , then move the carriage carrying the "grease spot" until the whole surface of the latter appears equally illuminated. *Great care being taken to keep the standard of light properly adjusted all through the tests at its certified value.*

N.B.—The *true* scale position will be found more accurately by taking the mean of the two positions of the carriage when the spot is *just perceptibly darker* and *lighter* respectively than the surrounding paper, or with a Flicker head when the Flicker disappears.

Note in each case the distance ( $d$ ) from standard to grease spot when the *plane of the lamp filament* is (a) parallel, (b) perpendicular to the axis of the bench, coloured glass being used in each case if necessary.

(5) Repeat 4 in 10% intervals of voltage across the lamp terminals up to within about 5% of the normal voltage for the lamp tested, and afterwards in 1% intervals to the maximum allowable.

(6) Calculate the C.P. ( $K$ ) of the lamp at each voltage from the relation

$$K = C \frac{(D-d)^2}{d^4}$$

where  $C$  = C.P. of the standard and ( $d$ ) = mean of all the bench readings of the grease spot as found in 4 above. Tabulate all your results as follows—

Name . . . . . Date . . . . .  
 Lamp tested: Make . . . . . Class . . . . . Normal Volts . . . . . Normal C.P. . . . . Resistance Cold . . . . .  
 Standard of Light: Type . . . . . C.P. . . . . H . . . . .

Current ( $I$ ) Amperes	E.D. ( $V$ ) Volts	Power ( $W$ ) Watts	Resistance (hot) $R = \frac{V}{I}$ (Ohms)	Plane of Filament and axis of Bench.				Total mean radius ( $d$ )	C.P. ( $K$ )	Efficiency in Watts per candle	Cost per candle- hour for power $P$
				Parallel.		Perpendicular.					
				Spot just perceptibly							
				dark	light	dark	light				

(7) Plot the following curves, to the same pair of axes and same scale for C.P. ( $K$ ) on the ordinates, between  $K$  and (1) amperes, (2) volts, (3) Watts, (4) resistance, (5) distance ( $d$ ), (6) efficiency, (7) the cost  $P$ .

(8) Calculate the ratio of the resistance "hot" to that "cold" for the lamp filament.

**Note.**—In calculating the cost  $P$  at the various C.P.s, assume that electrical energy costs 6d. per Board of Trade unit (1000 Watt-hours).

**Inferences.**—State at some length all the inferences which can be drawn from the above experimental results and curves.

## (22) Variation of Candle Power with direction around an Electric Incandescent Lamp.

**Introduction.**—With the introduction of new designs of electric glow lamps at the present day it is of considerable interest and often of importance to see the way in which the magnitude of the C.P. along a fixed or given direction changes as the lamp is turned

through various angles in both horizontal and vertical azimuths. The glow lamp to be tested should be capable of being turned in any direction about a point which is the centre of the principal part of the filament, and, further, this point must be in a line with the standard of light and centre of the Bunsen grease spot, or other "sight-box."

If the lamp thus adjusted is supplied at constant voltage and the C.P. measured at different angles in the horizontal plane as the lamp is turned completely through the circle, then the mean of all these C.P.s gives what is termed the "*mean horizontal C.P.*" If in addition the C.P. is now measured all round a vertical circle, the plane of which successively makes different angles with the axis of the photometer bench around a horizontal plane, then the mean of all the results will give what is termed the "*mean spherical C.P.*," and it will be found that the ratio

$$\frac{\text{mean spherical C.P.}}{\text{mean horizontal C.P.}} = K,$$

a constant which may be determined in the manner to be described presently.

The variation of C.P. around the lamp, as found in the present test, can best be seen by plotting "polar curves" for the different planes in which the filament is turned, using "polar co-ordinates." We will now consider briefly the approximate general form and method of plotting such curves.

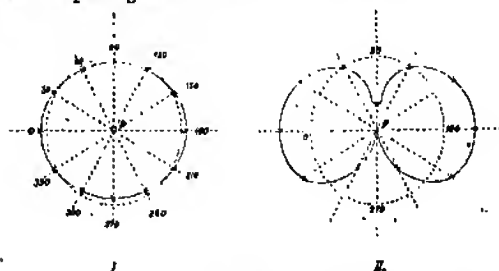


FIG. 24.

Fig. 24 I. and II. represent polar curves showing the distribution of luminosity in a horizontal and vertical plane respectively.

To obtain I, take any point or pole ( $P$ ), and with it as centre describe a circle, the radius of which represents to a suitable scale either the normal rated C.P. of the lamp, stamped on it by the makers, or else, the *mean horizontal C.P.* as determined from the experimental results. Divide the circle (shown dotted) into 12 equal divisions of  $30^\circ$  each all round from  $0^\circ$  to  $360^\circ$ , and draw a radial line from  $P$  through each, then setting off the C.P.s measured at the respective angles on these radial lines, the continuous curve is obtained on suitably joining them. In Fig. 24 I, the starting-point  $0^\circ$  would be that position of the lamp when the plane of the filament is parallel to the axis of the photometer bench. In II, the datum circle is drawn in the same way as before (and is shown dotted), and on setting off the C.P. measured at the respective angles as the lamp is now turned in a *vertical plane*, the continuous curve, somewhat of the shape shown, will be obtained. This polar curve II, will only represent the distribution of C.P. in that particular vertical plane which makes some noted angle with the above-mentioned zero on the horizontal plane or circle.

**Apparatus.**—Precisely the same as that mentioned in the preceding test, with the single exception that the glow lamp is now held in a special form of holder capable of turning through known angles in horizontal and vertical planes.

**Observations.**—(1) Connect up as indicated in Fig. 23, and adjust the pointers of the instruments  $V$  and  $A$  to zero, levelling the meters if necessary.

(2) Fix, in a manner most convenient for calculation, the distance  $D$  between standard and lamp to be tested (500 cms. say) and adjust the standard of light used to the proper C.P., either using the gas carburettor or otherwise.

(3) Close  $S$  and adjust  $R$  so as to obtain exactly the normal rated voltage across the lamp terminals, which must be kept *perfectly constant* throughout the whole set of tests.

(4) Adjust the lamp and its holder so that the principal part of the filament can rotate in a horizontal or vertical plane about some fairly definite point, the line joining which to the standard passes through the grease spot and is parallel to the photometer bench.

(5) With the voltage at exactly the normal value and the index

at zero on the horizontal scale for the plane of the filament parallel to the bench, measure the C.P. every 30° on the horizontal scale as the lamp is turned round (*vide obs. 4 and 6 of the last test*).

(6) With the index at 0° on the last-named scale measure the C.P. every 30° on the vertical scale as the lamp is turned round.

(7) Repeat 6 for the index at 45° and 90° on the horizontal scale, and tabulate all your results as follows—

Name . . .				Date . . .			
Lamp tested:—	Make . . .	Class . . .	Normal Volts . . .	C.P. . .	Resistance Paid . . .		
Standard of Light:	Type . . .			C.P. . .			
Horizontal scale readings.	Vertical scale readings for different horizontal angles.			Distance d	C.P. K	Moms K	Ratio H.S.K. V.H.K.
	0°	45°	90°				

(8) Plot the polar curves for horizontal and vertical distributions in the manner set forth above. The latter for each of the angles 0°, 45° and 90°.

### (23) Measurement of the Percentage Absorption of Light by different kinds of Shades and Lamp Globes.

**Introduction.**—In electric lighting particularly, and also in other methods of illumination, it is almost invariably the case that the lamp is partly or wholly enclosed in a globe or shade which is partly for use in softening the light, as we may express it, and partly for ornament. In arc lighting the opalescent globe is very generally used, while in the case of electric incandescent lighting either the bulbs of the lamps themselves are often made of opalescent, ground, frosted, coloured or other translucent forms of glass, or separate shades of such material enclose the ordinary clear glass bulb of the lamp. In all cases the result is a more evenly diffused light and a more uniform illumination, and one that is softer, so to speak, and less trying for the eyes. The introduction of such shades, however, usually diminishes considerably the outside illumination of the source owing to the absorption of light by the shade, but it should be borne in mind

that some of the light which is apparently absorbed is actually lost by reflection. As, in some cases, so much as 70% of the light produced is thus absorbed, it becomes of importance to determine the amount in particular cases, for it will be seen to materially affect the number of lamps really needed to illuminate satisfactorily a room of given area. The present test is arranged with the object of doing this, but no account will be taken of loss of light through reflection, as the measurements of this and absorption separately requires more elaborate methods.

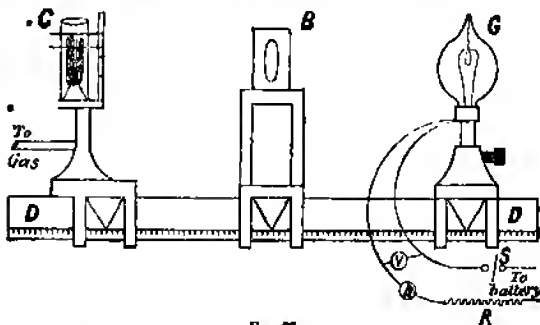


FIG. 25.

**Apparatus.**—Low reading ammeter *A* with long open scale (p. 559); high resistance voltmeter *V*; adjustable fairly high resistance *R* (p. 603); secondary battery and photometer bench *DD* complete, containing "Methven screen" or other standard (*C*) of light; "sight-box" *B* containing a Bunsen gas jet (p. 592); switch *S*; and an electric glow lamp *G* (say of 8 C.P.); shades to be tested.

**N.B.**—For particulars on the adjustment and use of the Methven screen standard of light, see Appendix, p. 595.

**Observations.**—(1) Fix, in a manner most convenient for calculation, the distance *D* between standard and glow lamp (500 cms. say), and adjust the standard to the proper C.P., either using the gas carburettor or otherwise.

(2) Connect up the glow lamp *G* as indicated in Fig. 25, and



adjust the pointers of  $V$  and  $A$  to zero if necessary and levelling them if required.

(3) Close  $S$  and alter  $R$  so as to obtain the normal voltage across the lamp terminals as read off on  $V$ . Then move the carriage carrying the "grease spot" until the whole surface of the latter appears equally illuminated, great care being taken to keep the standard of light properly adjusted throughout the tests.

N.B.—The true scale position will be found more accurately by taking the mean of the two positions of the carriage when the spot is just perceptibly darker and lighter, respectively, than the surrounding paper. In this way the mean distance ( $d$ ) from standard to grease spot should be taken when the plane of the lamp filament is (a) parallel, (b) at  $45^\circ$ , (c) perpendicular to the axis of the bench, and the volts and current noted at each (which must be kept constant).

(4) Now place a given shade to be tested for absorption over this plain glass bulbed lamp and repeat 3 for this and all other shades in succession, keeping the lamp voltage quite constant.

(5) Calculate the C.P. ( $K$ ) of the light with and without shades from the relation

$$K = C \frac{(D-d)^2}{d^2} \text{ candles,}$$

where  $C$  = the candle power of the standard and  $d$  = mean of all the bench readings of the grease spot as found in 3 above, and tabulate your results as follows—

NAME . . .						DATE . . .				
Glow Lamp; Normal Voltage . . .						Nature of glass bulb . . .				
Standard of Light; Type . . .						C.P. . . .				
Nature or kind of shade tested.	Volts $V$ .	Amps. $A$ .	Plane of Filament and axis of Bench			Total mean of all posi- tions ( $d$ ).	C.P. of light.		Absorp- tion by shade $100 \frac{K_0 - K_1}{K_0} \%$	
			Parallel.	At $45^\circ$ .	Perpendicular.		With- out shade $K_0$	With shade $K_1$		
			Spot just perceptibly							
			dark	light	dark		light	dark		light

**Inferences.**—State carefully all you can infer from the results of your experiments and point out their bearing on the lighting of rooms in general.

## The Photometry of Electric Arc Lamps.

**General Remarks.**—In photometric measurements of the present nature, many little difficulties exist which do not appear in the study of nearly all other sources of light. They arise from the fact that, in the first place, the intensity of the light is extremely fluctuating and very difficult to maintain constant for any appreciable length of time. In the next place, the intensities are usually so large that special standards of light have to be employed, and in addition, the general arrangements of the arc light source relatively to the photometer and standard have to be such that only a known fraction of the light to be measured is balanced against the standard. The chief difficulty, however, arises from the great difference between the colour of the arc light and that from all other common standards of light. So marked is this, both in the case of direct and alternating current arcs, that frequently the unpractised eye is unable to form anything like an accurate judgment between the amounts of illumination on a given surface due to each. Lastly, the arc is continually travelling round the carbons, thereby causing wide variations in the light emitted along the axis of the photometer bench. This effect on the correct readings of the photometer "sight box" for given positions can be minimized by taking the mean of several readings of the sight-box on the bench for as nearly as possible the same values of voltage and current supplied to the lamp.

As is well known there are some characteristic differences between continuous (direct) and alternating current arcs. In the former, the positive and negative carbons burn away at rates approximately in the proportion of 12:7 respectively, which, however, may vary from 1.2 to 4, according to the quality and type of carbons and the voltages and current supplied to the arc, the first-named ratio only holding approximately true for ordinary lamps with carbons of equal diameter, and using from 10 to 12 amps. at 45 to 50 volts and run with continuous currents. Peculiar to this type of lamp is the formation of a recess or "crater," as it is commonly called, at the end of the +<sup>ve</sup> carbon, the -<sup>ve</sup> assuming a conical pointed shape at the end.

For lighting purposes the lamp is always connected up and suspended so that the +<sup>m</sup> carbon is uppermost, and no second consideration is necessary to at once see that the distribution of light *all round* the arc (i.e. the spherical distribution) is far from being uniform. This determination, together with that of the spherical candle power (C.P.) for a given amount of power absorbed by the lamp and the regulation of the lamp mechanism, amongst other tests, is the object of the following investigation.

The distribution of intensity requires for its determination somewhat special arrangements for enabling the C.P. to be taken at different angles to the horizon line. This variation is measured in a vertical plane only, and there are several devices for carrying it out. One is to suspend the lamp from the ceiling by means of cords and pulleys or a pulley block, so that it can be raised or lowered to different heights above the central axis of the photometer bench; the light is then reflected by a suitably placed plane mirror (making an angle of 45° to the bench) along the axis of the bench to the sight-box; the centre of the mirror forming a right angle between the axis of the bench and the direction of the incident beam from the arc. The mirror is so arranged that the reflected rays always make an angle of 45° with the axis. The absorption of light or coefficient of reflection by the mirror at this angle is carefully measured and allowed for. Let this co-efficient or percentage of the total light striking the mirror, which is reflected, =  $K$ . Then C.P. of reflected

beam =  $\frac{K}{100} \times \text{C.P. of beam from the arc}$ , and this reflected beam is then measured against the standard. The distance of arc lamp from photometer sight-box then is reckoned as = distance between lamp and mirror + that between mirror and sight-box. This enables large C.P.s to be compared with comparatively small ones, which would otherwise necessitate a bench many yards long.

**STANDARD OF LIGHT.**—This should be as large as possible in magnitude, so as to keep the sight-box near the centre of the photometer bench, and thus minimize errors in its true position. In addition the colour of the light should approximate to that of the arc. The standard which fulfils these conditions in a fairly satisfactory manner is one consisting of an *over-run* glow lamp of,

any, 32 C.P. at normal voltage. If this is over-run some 5-8% in voltage, it will emit a much whiter light and one that is more nearly the colour of the arc. This lamp must be carefully standardized against a known standard of light at two or three definite and accurately noted voltages above normal. Probably 5% over normal will give a C.P. = about 40 or 45, and 7% over normal about 50-60 C.P. At this abnormal voltage the bulb will blacken inside fairly soon, and hence the lamp should not only be kept on for the shortest time, but should frequently be re-standardized.

Differences in colour between the two lights to be compared may to some extent be corrected by taking the readings of the slider carrying the sight-box when observing the balance of illumination of the latter through red and green glass in succession, the best kinds for the purpose being what are known commercially as "*signal-red*" and "*green*," and which should be so chosen that a bright sunlight viewed through the two together appears quite dark. The effect and object in using coloured glass is explained on p. 53.

There are really two kinds of efficiency determinations necessary in connection with arc lamps which are automatically self-regulating, namely—

(a) The "Commercial Efficiency" of the lamp as a whole reckoned in Watts per candle emitted, and which takes into account the total power in Watts absorbed by the lamp, i.e. in the arc and regulating mechanism.

(b) The "Nett Optical Efficiency," reckoned also as above, but taking into account only the power given to the arc itself and neglecting that absorbed in the regulating mechanisms.

The following tests are devised for the purpose of investigating these separately and comparing the results, and also of examining other very important points pertaining to arc lamps in general.

## (24) Measurement of the Commercial Efficiency of an Arc Lamp.

**Introduction.**—In the present instance the photometer bench being of considerable length, presumably, the two sources of light are placed one at each end and in a line with the photometer

sight-box, which will in future be termed the *screen*, for brevity sake.

**Apparatus.**—Photometer bench *BB*; fitted with a Bunsen grease-spot screen (*G*) (p. 592), placed inside a sight-box to prevent stray light, due to reflection from the walls of the room, falling on the screen, the walls and ceiling being as dull black as possible; standard known source of light (*L'*) consisting of an over-run 32 C.P. glow lamp, carefully standardized at a known voltage by a previous test.

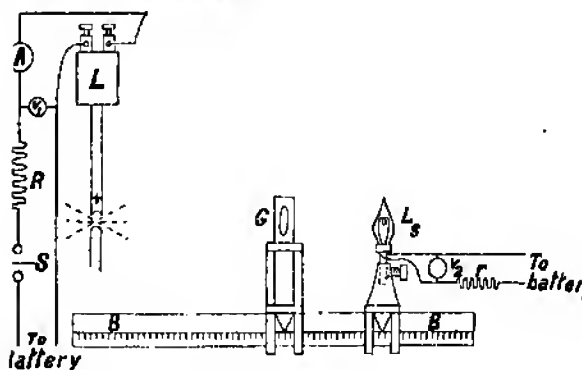


FIG. 26.

A voltmeter *V*<sub>2</sub>, preferably the same used in the calibration of the glow lamp, together with a rheostat *r* (p. 603) for reproducing the voltage of calibration. Arc lamp (*L*) to be tested, supported on a suitable stand, and placed in circuit with an ammeter *A*; voltmeter *V*<sub>1</sub>; rheostat *R* (p. 606), and switch *S*. A secondary battery should be available to feed both circuits in preference to a dynamo current, as the former gives a far more steady E.M.F. and better results than the latter.

**Observations.**—(1) Adjust the arc lamp in its cradle or stand, so that the point of contact of the carbons is at the same height above the bench as the centre of the screen and standard light. Centre the two carbons very carefully.

(2) Fix the distance *D* between arc and standard at some con-

venient amount for future calculations (say 600 cma.), and adjust the arc lamp so that the carbons are vertical.

(3) Connect up as shown in Fig. 26, and adjust the pointers of  $A$ ,  $V_1$  and  $V_2$  to zero if necessary. Vary  $r$  so as to give  $L$ , the voltage as read off on  $V_2$  at which it was standardized last, when it will then give a definite known C.P.

(4) With  $R$  full in, close  $S$ , and vary  $R$  so that the arc just burns with the carbons in equilibrium. Now quickly adjust the position of the sight-box, so that the grease spot appears equally illuminated all over each side. Note its scale reading ( $d$ ) from the standard, the volts  $V_1$ ,  $V_2$  and the amps.  $A$ .

Note.— $V_2$  must be kept rigorously constant during this and the following observations. The scale reading  $d$  can be obtained most accurately by reading it when the grease spot is just perceptibly darker and lighter respectively than the surrounding paper. This should be done, using red and green glass in addition to the naked eye, and the mean of all the readings recorded. The reading of  $V_1$  and  $A$  must be constant during the taking of the above readings.

(5) Readjust  $R$  and repeat 4 for about ten different values of  $V_2$ , rising by about equal increments to 60 volts or so,  $V_1$  being constant.

Each of the readings in 4 and 5 should consist of a group of 3 or 4 observations with  $V_1$  and  $A$  constant, so that a mean may be taken which would allow for alteration in C.P. due to the arc travelling round the carbons.

Tabulate your results as follows—

Name . . .				Date . . .				
Arc lamp tested: No. . . .				N. No. . . .		Type . . .		
Type of carbons . . .				Size of post vs . . .		Size of negative . . .		
Standard light: Type . . .				Candle power $K_p$ . . .		Ammeter Resist. . . . Ohms.		
Volts on Standard $V_2$	Amps. through arc lamp $A$	Volts across lamp $V_1$	Watts given to lamp $AV_1$	Distance.		C.F. of "A.C." $K_s = \frac{(D-d)^2}{d^2} K_p$	Commercial Efficiency $\frac{AV_1}{K_s}$	Cost per candle hour for power.
				d.	D-d.			

(6) The voltmeter used for  $V_1$ , especially if a hot wire, must be shunted, not directly to the lamp, but to the lamp and ammeter  $A$  combined. The volts lost in  $A$  can be calculated and sub-

tracted from that shown on  $V_1$  in order to get the *true volts* on the lamp.

The ammeter resistance is required for this correction and can be found approximately by the Wheatstone Bridge.

(7) Plot the following curves on the same sheet of curve-paper between C.P. as ordinates in each case, and (i) Volts  $V_1$ , (ii) Amps.  $A$ , (iii) Watts  $AV_1$ , (iv) Efficiency as abscissae.

(8) Compare the above cost per candle hour for power at 54 per unit at normal voltage across the arc lamp with that of a glow lamp of equal C.P., taking 3 Watts per candle at normal voltage. The price of energy being the same.

**Inferences.**—State clearly all you can infer from your experimental results.

## (25) Determination of the Nett Optical Efficiency of an Arc Lamp.

**Introduction.**—This test is similar to the last, with the following exceptions—

Place the voltmeter  $V_1$ , which should be of a sensitive high resistance type, *across the arc* instead of the lamp terminals as in the preceding test. This can be done by connecting it to two spring clips, which make good contact with the carbons about two inches from their ends next to the arc. The ammeter ( $A$ ) must now be so arranged in the circuit that it measures the current through the arc without taking into account that passed by any shunt-coil which the lamp may happen to have.

**Apparatus.**—The same as for the commercial efficiency test, and in addition the two necessary spring clips.

**Observations.**—Repeat those of the foregoing test exactly as there indicated.

Connect up as in Fig. 26, with the exceptions noted above as regards the position of the ammeter and voltmeter.

Compare the efficiencies obtained from the two tests, and also the costs per candle hour for power at the same price.

## (26) Determination of the Distribution of Light from an Electric Arc.

**Introduction.**—The distribution in the case of an arc light is obtained by measuring the O.P. at various angles to the horizon, in one single vertical plane containing the central axis of the photometer bar.

To enable this to be done some arrangement, similar to the one briefly described under "General remarks" on arc light photometry, is necessary.

The author, however, has devised a simple form of "*cradles*" in which to fix the lamps, and which is illustrated and described in the Appendix, p. 587.

• The difficulty arising in the use of such an arrangement is due to the fact that most arc lamps will not continue to self-regulate when placed in a slanting position. The author, however, finds that, with a suitable type of lamp, there is practically no difficulty from the above cause, until the cradle makes an angle of about 50° with the horizontal, and for just the one or two readings after this it is easy to help the mechanism by hand in order to maintain the "intake" of electrical power by the lamp constant.

**Apparatus.**—Precisely that mentioned for the test No. 24, p. 63, on "Commercial Efficiency," except that the cradle is now required where just an ordinary stand would have done in that test.

**Observations.**—(1) Repeat 1-3 of the above-cited test, seeing in addition that the carbons touch at a point which is in a line with the centre of the axle of the cradle, and that their axes coincide.

(2) Set the cradle with its pointer at zero, when the carbons will be vertically over one another. With  $R$  full in, close  $S$ , and vary  $R$  so that the lamp takes its normal voltage and current and burns quite steadily, then quickly balance (by moving the screen), in the manner set forth in observation 4 of the test cited; repeat this three or four times for the same values of  $A$  and  $V_1$ , and record the mean in the table.

(3) Repeat 2 above, for the same values of  $A$  and  $V_1$ , for every 10° through which the cradle is turned, up to 70° or 80°, when



the axis of the carbons will be nearly parallel with the photometer bench, and tabulate as in the table for test 24 cited, substituting the heading "Angle between carbons and horizon" for the cost, etc., in the last column of the table.

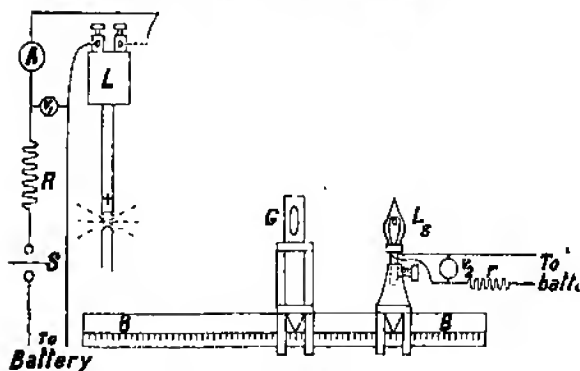


FIG. 27.

(4) Repeat 2-3 for a considerably lower current  $A$  than the normal, but one at which the arc burns properly.

(5) Plot the *Polar Diagram* or curves of distribution of light from the arc at various angles for each current used in the manner described below.

**Inferences.**—State clearly all you can infer from your experimental results, and point out their bearing on the lighting of streets and large areas by means of arc lamps.

Determine from your results the mean spherical efficiency which =  $\frac{1}{4}$  horizontal efficiency +  $\frac{3}{4}$  max. efficiency).

**Note.**—This may vary from 0.050 to 0.200, depending on the diameter and quality of the carbons, and is the ratio of the nominal power in Watts, as given to the lamp in observation (2) above, to the mean spherical C.P. resulting.

#### PLOT OF POLAR DIAGRAM AND DISTRIBUTION OF LIGHT FROM ARC.

Let  $D$  be the junction of the + and - carbons, i. e. centre of arc.

Let  $DB$  represent the maximum C.P. obtained for some position of the arc, then with  $D$  as centre and  $DB$  as radius, draw the semi-circle  $ABC$ . Divide this into eighteen equal parts, each of which will therefore =  $10^\circ$  of arc, and draw radii to the points of intersection so formed. Now set off to the same scale as  $DB$ , the various C.P.s measured, along the respective radii from  $D$ , representing the angles in which they were measured. Then the curve  $DGFH$  drawn through these points is the polar diagram of C.P.s from the arc.

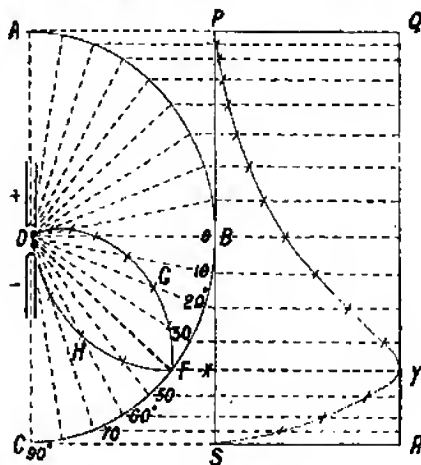


Fig. 26

The distribution corresponding to this polar diagram is obtained as follows—

Draw  $PRS$  through  $B$  parallel and equal to  $ADC$ .

Through each of the points of division on the semi-circle  $ABC$  draw lines parallel to  $DB$ , and therefore perpendicular to  $PBS$ . From  $PS$  on these set off lengths proportional to the respective C.P.s at the corresponding angles. Thus, for instance,  $XY = DF = \text{maximum C.P.}$  and so on for the rest. Now complete

the rectangle  $PQYRS$  and draw the second curve  $PYS$ . Then we have for the arc lamp—

$$\text{Mean spherical C.P.} = \frac{\text{Area of curve } PYS}{\text{rectangle } PQRS} \times \text{max. C.P.} \\ = \left(\frac{1}{2} \text{ horizontal C.P.} + \frac{1}{2} \text{ max. C.P.}\right) \text{ approx.}$$

The curve  $PYS$  shows the manner in which the illumination of streets falls off with direct current arc lamps at different distances from the lamp for a given height above the ground.

### (27) Other Tests on Arc Lamps.

**DETERMINATION OF THE EFFECT OF CARBONS OF DIFFERENT DIAMETERS AND QUALITY ON THE SPHERICAL C.P. AND SPHERICAL EFFICIENCY.**

**Notes.**—In this test care must be taken to vary *only one* thing at a time, as for instance—

(a) Vary the diameters only for exactly the same quality of carbon, all other conditions being constant.

(b) Vary the quality only for exactly the same diameter of carbon, all other conditions being constant, as for instance the amount of power supplied to the arc. The spherical C.P. and efficiency is then measured in each of the cases a and b in the manner just described.

The results should be tabulated in a convenient manner. If possible a curve should be drawn between each separate pair of variables, and, lastly, inferences deduced from the experimental results.

### (28) Determination of the Relation between Voltage and Current respectively, and the loss in grammes per hour of Positive and Negative Carbons.

**Notes.**—In this test, as was also mentioned in the last, only one thing must be varied at one and the same time. Thus—

(a) For the same voltage, measure the loss in grammes of the

same or exactly similar +<sup>ve</sup> and -<sup>ve</sup> carbon occurring in the same interval of time with different currents.

(b) For the same current, measure the loss in grammes of the same or exactly similar +<sup>ve</sup> and -<sup>ve</sup> carbon occurring in the same time with different voltages.

The results should be tabulated in a convenient manner, and if possible the following curves drawn—

Two between volts and amps. respectively on the abscissæ and losses in grammes per hour of +<sup>ve</sup> carbon as ordinates.

Two between volts and amps. as before, with losses in grammes per hour of -<sup>ve</sup> carbon as ordinates.

All on the same sheet of curve paper.

Carefully deduce the inferences obtainable from the results of the tests.

## (29) Relation between Voltage and Length of Arc (with Constant Current through it).

**Introduction.**—This test, like the next one, is important, as it indicates why certain types of lamps can be run at higher voltages than others, while in conjunction with the results of a corresponding test for obtaining the Polar Diagram of the lamp, the effect of the length of arc on the distribution of light over the lower hemisphere is clearly indicated. The reader should peruse the remarks under "Introduction" in the next test which apply to the present one also.

**Apparatus.**—Precisely that for test No. 30.

**Observations.**—(1) Connect up as in Fig. 30, and set  $A$  and  $V$  to zero if necessary.

(2) With  $(H)$  full in, close  $S$  and "strike" the arc by bringing the carbons together for an instant, and then quickly separating them,  $R$  being reduced to keep the arc burning.

(3) By varying  $R$ , obtain a series of arc lengths between about  $\frac{1}{4}$ " and the maximum possible by applying different voltages across it, the current being kept as constant as possible all the time at the most convenient value to be found by trial. Then after rapidly moving  $L$  to obtain the sharpest image  $I$  on  $G$  of each arc length, quickly measure  $L$ , and note  $x$ ,  $y$ ,  $A$  and  $V$ .

**Note.**—Time should be allowed for the carbons to burn to shape, and for the arc to become steady before readings are taken.

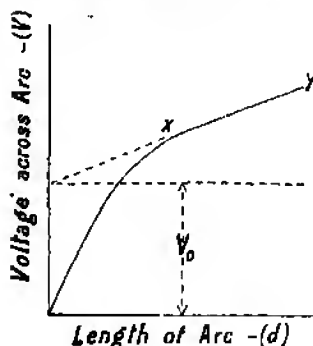


FIG. 29.

Tabulate your results exactly as in the last test, and plot curves having values of  $V$  and  $R$  as ordinates with length of arc ( $d$ ) as abscissae.

Find the constant ( $a$ ) in the equation—

$$V = V_0 + a.d.$$

to the working part of the curve, Fig. 29.

**Inferences.** — What

can you deduce from the results of your test?

### (30) Relation between the Current through an Electric Arc and the Voltage across it (for a constant Length of Arc).

**Introduction.**—The present test has an important bearing on the supply of electrical energy to "open," "enclosed," and "flame" arc lamps in view of the length of arc normally employed in these three distinctive types being different in practice. The voltage across the arc can be obtained by a high resistance voltmeter connected to two spring clips placed on the carbons as close to their tips as is safe without risk of fusion.

The voltage thus measured will be that necessary for overcoming the apparent resistance of the arc made up of the back E.M.F. of the arc + the "ohmic drop" in the arc due to its ohmic resistance.

If the voltmeter is connected to the lump terminals it will measure the above-named apparent resistances + the additional "ohmic drop" between carbon tips and terminals.

The length of arc may be found in one of two ways: (1) by throwing an image of the arc on to a screen at a known distance away, by means of a double convex lens, when from the length of image and the distances of the lens from arc and screen the length of arc itself is at once obtainable; (2) by placing a gauge of known length, about equal to that of the arc in front of the latter, and measuring the shadow of the gauge on the screen, when from the length of shadow, gauge and the distances, the length of arc is obtained.

**Apparatus.**—Hand-feed arc lamp *B* with terminals *TT*; double convex lens *L*, mounted on sliding base; ground or milk glass screen *G*; ammeter *A*; voltmeter *V*; variable rheostat *R*; switch *S* and source of supply *E*.

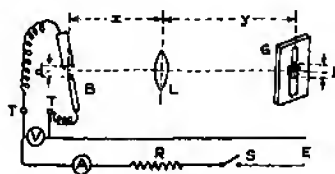


FIG. 30.

**Observations.**—(1) Connect up as in Fig. 30, and adjust the pointers of *A* and *V* to zero if necessary.

(2) With (*R*) full in, close *S* and "strike" the arc by bringing the carbons together for an instant, and then quickly separating them, *R* being reduced to keep the arc burning, which must be carefully watched.

(3) Adjust the arc to a convenient length, say  $\frac{1}{8}$ " to  $\frac{1}{4}$ ", and move *L* until the clearest image *I* is obtained on *G*, then quickly measure the length of *I* on *G*, and note the readings of *V* and *A* and the distances *x* and *y*.

(4) With the length of *I* constant, vary *R* so as to obtain a series of values of *V* and *A* between 0 and, say, 25 amps.—*x* and *y* being constant, and the arc adjusted to keep *I* constant.

(5) Repeat 3 and 4 for constant lengths of arc of about  $\frac{1}{8}$ " and  $\frac{1}{4}$ ", and tabulate your results as follows—

Distances.		Lengths of		Volts $V$ .	Amps. $A$ .	Apparent Resistance $R = \frac{V}{A}$ ohms.
$x$ .	$y$ .	Image ( $I$ ).	Arc ( $I$ ) $= \frac{x}{y} \times I$ .			

(6) Plot to the same axes, curves having values  $A$  as abscissae with both  $V$  and  $R$  as ordinates.

**Inferences.**—What can you deduce from the results of the test?

### (31) Examination of Alternating Current Arcs.

**General Remarks.**—The alternating current arc possesses many characteristic and interesting features which are absent in the case of the continuous current arc. Thus for instance the two carbons consume away at approximately equal rates. The colour of the rays is quite different, being much more purple than in the direct current arc. Again, more energy is needed for the same volume of light emitted, and the arc gives out a rhythmic hum if it is burning properly.

In addition the true power  $W$  given to the lamp may be considerably less than the apparent power  $AV$ , i.e. the product of the alternate current ammeter and voltmeter readings. Thus the power factor which  $= \frac{W}{AV}$  may be very low and even down to 0.50 in an alternating current arc lamp.

The following additional investigations should be carried out on this type of lamp, namely—

The effect on the C.P. of variations of (a) voltage, (b) current, (c) frequency, (d) quality of carbon.

The effect on the angle of phase difference or power factor of (e) quality of carbon, (f) cored and uncored carbons, (g) hissing of the arc.

The relative amounts of power absorbed by the arc itself and by the regulating mechanism should be investigated.

Many of the above tests can only be employed on hand-regulated lamps.

### (32) Measurement of the Internal Resistance of Secondary Cells.

**Introduction.**—The following method is the best for measuring the working value of the internal resistance of a storage cell or battery of such. Owing to the very low resistance met with usually in this kind of cell the ordinary methods are practically inapplicable, and in the present case the cell is being tested more or less under working conditions.

If a battery is being tested the total internal resistance can be obtained at once, and if the cells are all of the same size, make, and type, the resistance of each cell can be deduced, probably with considerable accuracy, by dividing the total resistance so obtained by the number of cells and thus obtaining the average resistance per cell. It should be remembered that the internal resistance of any cell is not a fixed and invariable quantity but depends on several things, thus, for instance, on the density of the sulphuric acid solution which is continually changing according to the amount of discharge, or charge of the cell. It is interesting to note in this connection that the resistance of a solution of dilute sulphuric acid is least at a specific gravity of about 1.220 and increases from this in either direction, i.e. for a rise or fall in density. Again, the internal resistance will depend on the condition the plates are in, and will be greater if they are "sulphated" than if in good condition.

**Apparatus.**—The cell or cells (*B*) to be tested; voltmeter *V* of sufficiently large resistance, and having a long open scale, enabling small differences to be read accurately; ammeter *A* capable of reading up to the maximum current to be taken from the cell; key *K*; switch *S*; carbon rheostat *R* (p. 597).

**Observations.**—(1) Connect up as in Fig. 31, and adjust the pointers of *V* and *A* to zero, levelling the instruments if necessary.

(2) With *S* open, close *K* and note the reading *E* on the voltmeter. This is therefore the E.M.F. of the cell in volts, since only an extremely small current is flowing.

(3) Close both *K* and *S* and adjust *R* so as to obtain about



1/10th of the maximum current output from *B*. Note simultaneously the readings on *A* and *V*, which latter now gives the *terminal* P.D. (*V*) in volts.

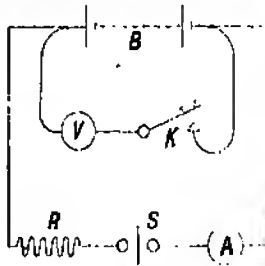


FIG. 31.

(4) Repeat 2 and 3 for about ten different currents rising by about equal increments to the maximum.

(5) Calculate the working value of the internal resistance *b* of the cell or battery from the relation

$$b = \frac{E - V}{A} \text{ ohms,}$$

and tabulate your results as follows—

NAME . . . . . DATE . . . . .  
Cell tested: Make . . . . . Type . . . . . No. of Plates = . . . . . Size of Plates = . . . . .  
Distance between Plates = . . . . . Approx. Sp. Gr. of Solution = . . . . .

E.M.F. <i>E</i> Volts.	P.D. <i>V</i> Volts.	Current <i>A</i> Amperes.	Internal Resistance <i>b</i> Ohms.	Internal Resistance per Cell for a Battery.	Mean Internal Resistance.

(6) Plot 2 curves having values of *V* and (*b*) as ordinates and *A* as abscissae. Show that the tangent of the angle of slope (from the horizontal) of the *V* and *A* curve = the internal resistance (*b*).

### (33) Measurement of the Efficiency and Storage Capacity of Secondary Cells.

**Introduction.**—Secondary cells may be divided into two main divisions, namely—the “Fauré” or *pasted type*, and the “Planté” or *non-pasted type*. The chemical changes occurring in either class, during charge and discharge, are precisely alike, but the reader is referred to ordinary text-books of *Electrical Engineering*—for instance, *Electrical Engineering in Theory and Practice*, by the author—for such changes which hardly come under the scope of the present work.

The secondary or storage cell has taken up so prominent a

position at the present day in both electric lighting and electric traction that the method of measuring the efficiency and storage capacity of any type of cell, or perhaps more particularly the relative behaviour of different types under the same conditions, is a matter now of paramount importance to every electrical engineer. A good deal may be said with regard to the precise mode of testing such cells, and in this connection much depends on the duty which they have to perform in actual practice. Any laboratory test of such cells will be worthless almost, from a practical point of view, unless it is carried out under conditions as nearly as possible alike to those the cell will work under in its everyday use. Thus, for instance, take a battery employed for merely lighting purposes, say at a central electricity supply station. It is never resting idle and never merely giving either the full load discharge or any other constant output, for the load which it has to take varies with the hour, day, and season of the year, from often next to nothing, to full load and sometimes a considerable percentage overload for short periods. Thus it will be seen that in this instance any test to be of value must be carried out as nearly as possible under these conditions, and for months continuously, too, instead of, perhaps, only for two or three weeks always at full load and with, say, a night's rest in between each such discharge.

Again, in the case of electric traction work, the above remarks do not all apply, for instance, usually a battery used in this kind of work in sub-stations is relieved of discharge between midnight and about 7 a.m. in the morning, during which period it is charged. When used for portable work, as in autocars and tramcars, it is subject to both rapid and wide fluctuations of output and often to excessive jolting. Hence the test on a cell required for this kind of work should be a very stringent one, automatic jolting gear being provided to operate on the cell while being discharged, while this latter must often be abnormal. Practically the Faure or pasted type of cell is the only one available for self-contained autocar traction, as weight forbids the use of the Planté type. As one instance of a traction type of pasted cell which will stand periods of excessive discharge and the wear of the solution against the plates and yet have a long life, the Hindland secondary cell may be instanced, and tests extending over years amply justify this.

The efficiency of any secondary cell or battery can be reckoned in one of two ways, namely, the—

Quantity efficiency, or Ampere-hour efficiency

$$= \frac{\text{Ampere-hours given out}}{\text{Ampere-hours put in}}$$

Energy efficiency, or Watt-hour efficiency

$$= \frac{\text{Watt-hours given out}}{\text{Watt-hours put in}}$$

Each of these will depend to a certain extent on the relative periods of charge, rest, and discharge, and also on the current density or rate of discharge reckoned say in amperes per unit of area of positive plate. The greater this is the less will be the quantity efficiency, and also the energy efficiency, though the latter not to the same extent as the former.

It may here be remarked that the quantity efficiency may be as high as 94% when the current density is low and the cell used under favourable conditions, whereas the energy efficiency cannot exceed 80% from the fact that the average *normal* *voltage* of a cell *on discharge* is 2.0 volts approximate and the average *voltage* *needed to charge* being 2.5 about. These two efficiencies in practice may be taken more nearly as about 75% and 65% respectively.

The CAPACITY of any secondary cell may be expressed in one of two ways, namely, either as the ampere-hours or as the Watt-hours which it is capable of giving as a *useful discharge*. The term *commercial capacity* might be given to the number denoting the ampere-hours or the Watt-hours per lb. of plate (taking both + and - together) or per lb. of cell complete, including acid, etc.

At the present day, owing to there being so many forms and methods of building, the latter mode of reckoning the capacity is the only one available when comparing different types of cells.

A secondary cell may be charged either (1) at constant P.D. or (2) at constant current. In the first case a fairly heavy rush of current takes place at starting, and the method would be unsuitable for use on some types of pasted cells from the risk of the plates buckling. The second method is the one nearly always employed in practice and is the one which will here be considered.

The cell should not be discharged *normally* below 1.80 volts on closed circuit, since it will then become practically useless for lighting circuits, and there is also the danger of the plates "*sulphating*" rapidly below this limit. For the latter reason it should not be allowed to rest in this discharged condition.

**Apparatus.**—Cell *B* to be tested; sensitive voltmeter (*V*) with

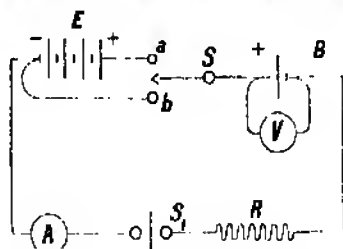


Fig. 32.

open scale; ammeter (*A*); switch *S*<sub>1</sub>; carbon rheostat *R* (p. 697); two-way switch *S*; source of charging E.M.F. (*E*); hydrometer and weighing arrangements if the latter should be required.

**Observations.**—(1) Assuming that the cell to be tested is not already set up, but is still as received from the makers. First weigh each complete set of plates, "Positives" and also "Negatives," separately after dusting them. Also weigh the containing vessel, and the dilute sulphuric acid solution (of the specific gravity authorized for that particular cell), which is sufficient to cover the plates and be about one inch above their tops. Measure the size and thickness of the plates.

(2) Set up the cell properly, connecting up as indicated in Fig. 31, and adjust the pointers of *V* and *A* to zero if necessary.

(3) More as a matter of interest than otherwise, carefully note the sp. gr. of the acid solution before and immediately after putting it into the cell by means of the hydrometer, and then note the readings of this latter and the time frequently, while the sp. gr. is rapidly altering and until it becomes constant.

**Note.**—In all cases exercise great care in keeping the hydrometer away from the sides of the vessel and plates; if this is not done it will give totally erroneous readings due to adhesion.

(4) If the sp. gr. of the acid solution is constant note it, then with  $R$  at its maximum and  $S$  on contact  $a$ , note the time on closing  $S_1$  and quickly adjust the current on  $A$  to the "normal" for this cell by means of  $R$ .

(5) Keep this current constant in strength until the acid becomes milky in appearance throughout—commonly known as *boiling* and due to bubbles of gas liberated from the plates. Note the readings of the hydrometer and voltmeter and the time frequently while they are varying rather rapidly, but less often as they vary more slowly, and, lastly, open  $S_1$  when the cell is completely charged.

N.B.—Probably this first charge will last from at least 16 to something like 30 hours before the cell thoroughly comes up to the "boil," and in no case should it be stopped in the first 12 hours except for a minute or so. Beyond keeping the current constant from beginning to end the other readings during the middle stages of charge need probably be only taken every 1 or 2 hours about.

Tabulate your results as follows—

CHARGE.

NAME . . . . . DATE . . . . .

Name of Cell . . . . . Type . . . . . Normal rated capacity . . . . . Amp. hours . . . . .

Weight of plates: Positive = . . . lbs.; Negative = . . . lbs.; Vented = . . . lbs.; Acid = . . . lbs.

Thickness of plates: Positive = . . . . . Negative = . . . . .

Total surface of Positive = . . . sq. ft.; Plate volume = . . . . . Acid volume = . . . . . Ratio = . . . . .

Number of Charge.	Ampere $A$ .	Terminal P.D. ( $V$ ) Volts.	Time in Hours.	Sp. gr. of Acid.	Input Amp. hours.	Input Watt-hours.

(6) Take note of the period of *rest* (if any) which the cell has had since the last charge, note the open circuit P.D. at its terminals and the sp. gr. Then put  $S$  to ( $b$ ) and close  $S_1$  at a noted instant of time, quickly adjusting  $A$  to the *normal* discharge value for the cell, which must be kept constant by  $R$ . Note the P.D. on  $V$  and the sp. gr., and the time frequently while they are varying somewhat rapidly, but less often as they vary more slowly.

Open  $S_1$  every half-hour, say for the shortest time necessary to just take the "open circuit" volts. noting the time at each.

(7) Continue the discharge until the terminal voltage falls to 1.80, then open  $S_1$  and tabulate your results as follows—

## DISCHARGE.

Number of Discharge	Time in Hours	Sp. gr. of Acid.	Amps. A.	Terminal Voltage		Internal Resistance h.	Output Capacity		Efficiency	
				Closed circuit V.	Open circuit E.		Amp- hours.	Watt- hours.	Amp- hours.	Watt- hours.

(8) Repeat tests 4-7 until the charge and discharge curves practically coincide, indicating that the cell has attained a good normal working state, and take note of the length of rests between charge and discharge.

(9) Take a discharge, as per 6 and 7, for 50% under- and also "over"-normal rate.

(10) At the conclusion of all the tests carefully observe whether any appreciable "buckling" or disintegration of the plates has occurred.

(11) Calculate the capacity of the cell in both amp-hours and Watt-hours per lb. of total plates and per lb. of cell complete with acid. Also calculate the current density used per sq. ft. of + plate, reckoning both sides of each.

(12) Plot the following curves, all like ones being on one sheet—

(a) Internal resistance in ohms as ordinates and times in hours during discharge as abscissae.

(b) Time in hours as abscissae, with voltage and sp. gr. as ordinates in each case for both charge and discharge.

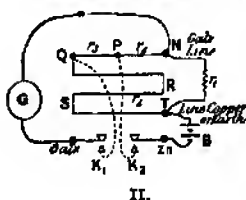
(c) Current density as abscissae and amp-hours output as ordinates.

(d) Current in amperes as abscissae and the quantity and energy efficiency as ordinates.

### (34) Measurement of Resistance by the "Post Office" Pattern of the Wheatstone Bridge.

**Introduction.**—It is assumed that the first principles of a Wheatstone Bridge (W.B.) have already been studied from an ordinary text-book. The Post Office (P.O.) pattern, Fig. 33 II., is merely a specially-arranged and compact form of W.B. placed in

a suitable box for portable purposes. If the principle and action of a W.R. is understood at all, and the stamping opposite the various terminals in the P.O. form observed, it ought to be impossible to couple up incorrectly. Each of the "proportional arms"  $r_3$  and  $r_4$  consists of three resistance coils of 10, 100, and 1000 ohms each respectively, hence the ratio  $r_3$  or  $r_4$  can be made



II.

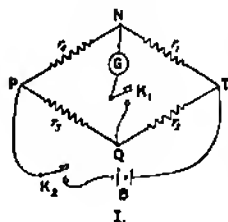


FIG. 33.

a very simple number.  $QRST$  (Fig. 33 II.) is the "adjustable arm"  $r_2$ , and it consists of 16 different coils and one infinity plug either at  $Q$ ,  $R$ , or  $S$ . The value of  $r_2$  can be made anything from 1 to 11,110 ohms. Opposite two of the terminals ( $N$  and  $T$ ) is marked (Galvanometer Line) and (Line Copper or Earth) respectively. This is because the P.O. form is primarily intended for measuring the metallic and insulation resistance of telegraph lines, and hence in the first case that line would be joined to  $N$  and  $T$ , and in the second case only one end to  $N$ , the other being free

and insulated,  $T$  then being put to earth. As therefore we are measuring metallic resistances ( $r_1$ ) it is put between  $N$  and  $T$ . The terminals to which the battery  $B$  must be connected are equally obvious. The white dotted lines on the top show where the under contacts of the keys  $K_1$  and  $K_2$  are joined to, inside the box. In any form of W.R. variation of the battery E.M.F. or its resistance or that of the galvanometer ( $G$ ) has no effect on the accuracy of the measurement. The sensitiveness of the test, though principally depending on that of  $G$ , can be increased within limits by using a larger E.M.F. and making  $r_1$ ,  $r_2$ ,  $r_3$  and  $r_4$  as nearly equal as possible. The battery key  $K_2$  must always be pressed before the galvanometer key  $K_1$  to allow the currents in the

arms to become steady before pressing  $K_1$ . The battery key should be pressed for no longer in order to prevent the coils being heated by the current and their resistance thereby altered. *It should also be broken last to avoid the risk of damaging  $G$  by inductive kicks when measuring inductive resistances.* In inserting plugs *press in tightly and give about  $\frac{1}{8}$  of a turn to insure good electrical contact.* Reverse this operation when removing them. The ends of all connecting wires should be scraped clean.

**Apparatus.**—P.O. Bridge; sensitive galvanometer  $G$  (p. 571); 2 or 3 Leclanché cells  $B$ .

**Observations.**—(1) Connect up as indicated in Fig. 33 II., and adjust the galvanometer needle to zero.

(2) Note once for all the direction in which  $G$  deflects when  $\phi_2$  Fig. 33 II. is too large to give balance (done by taking out "Inf" in  $r_2$  with, say,  $r_3 = r_4 = 10$ ).

**Note.**—Until balance is nearly obtained, only tap  $K_1$  for a fraction of a second.

(3) Make  $r_3 = r_4 = 10$  and balance the bridge by altering  $r_2$  so as to get no deflection on pressing  $K_4$  and then  $K_1$ . If it is impossible to get exact balance, note the steady deflection when  $r_2$  is just too large and too small, and calculate the correct intermediate resistance to give balance, by proportion. Thus if  $d_1$  = steady deflection of the galvanometer to one side of zero for the adjustable arm =  $R_1$ , and  $d_2$  = that to the other side of zero for the adjustable arm =  $R_2$ , then if  $R_1$  is greater than  $R_2$  we have  $(R_1 - R_2)$  ohms corresponding to a deflection of  $(d_1 + d_2)$  scale divisions,

and  $\therefore d_2$  corresponds to  $(R_1 - R_2) \frac{d_2}{d_1 + d_2}$  ohms.

Hence the resistance of the arm, which would give just no deflection (the required condition)

$$= R_2 + (R_1 - R_2) \frac{d_2}{d_1 + d_2} \text{ ohms} = r_2.$$

(4) In order to obtain the true resistance ( $r_1$ ) of the unknown which is being measured, without the process of interpolation mentioned in the latter part of 3 above, the value of  $r_3$  or  $r_4$  may be varied. Thus instead of  $\frac{r_1}{r_2}$  being  $\approx \frac{1}{2}$  or 1 as in 3 above, we



might have  $\frac{r_1}{r_2} = \frac{1000}{100}, \frac{1000}{1000}, \frac{1000}{10000}$ , or  $\frac{1000}{10000}$ , depending on the value of the unknown  $r_1$ . In many cases this will be equivalent to having decimals of an ohm in the adjustable arm ( $r_2$ ). Hence, increase or decrease the ratio of  $\frac{r_1}{r_2}$  and adjust  $r_2$  so that on pressing  $K_1$  and then  $K_2$  no deflection whatever occurs on the galvanometer. Then note the values  $r_2, r_3$  and  $r_4$ .

N.B.—If the unknown resistance  $r_1$  is greater than 11,110 ohms, then  $r_4$  will be greater than  $r_3$ , but if ( $r_1$ ) is less than 11,110 ohms, then  $r_4$  may be either—, or less than  $r_3$ . Tabulate as follows—

Resistance tested.	Proportional Arms.		Adjustable Arm $r_2$	Unknown Resistance $r_1 = \frac{r_3}{r_4} \times r_2$	Mean $r_1$ .
	$r_3$	$r_4$			

Note.—The limits of the P.O. Bridge are  $(\frac{1000}{10000} \times 1) = 0.01$  ohm and  $(\frac{10000}{100} \times 11,110) = 1,111,000$  ohms, but measurements become less accurate as they approach these limits.

### (35) Measurement of the Armature Resistance of Dynamos and Motors, and of the Copper Resistance of Transformers and Electric Light Cables. (Potential Difference Method.)

**Introduction.**—The Wheatstone Bridge is inapplicable for measuring very low resistances, and even if such were just within its range, the measurement would not be accurate owing to errors introduced by the variable contact resistances in the circuit. The following method, which depends directly on the definition of resistance, can be used to accurately measure very low resistances, such as are met with in large electric light cables, the armatures of dynamos and motors, and the low tension coils of transformers.

The P.D. at the terminals of each resistance can be measured relatively by a sensitive galvanometer, whose resistance is large

compared with that between the two points to which it is applied. Under these conditions its insertion will not lower the P.D. to be measured. If it is a reflecting instrument the scale deflections will be proportional to the P.D.

The most suitable instrument for a workshop test, which as a rule does not admit of the use of a delicate galvanometer, is a low reading voltmeter, having fairly large resistance, and reading to about 1 or 1.5 volts for a full scale deflection. Such an instrument, although not nearly as sensitive to small differences of potential as the galvanometer, has the advantage usually of being more portable, and also less easily affected by magnetic fields in the vicinity.

**Apparatus.**—Known standard low resistance  $R$  of about 0.01 ohm (Fig. 273); low resistance  $r$  to be tested; Pohl's commutator  $C$  (p. 584); secondary cell  $B$ ; rheostat  $R_h$  (p. 597); fairly high resistance galvanometer (p. 569) or low reading voltmeter  $G$ , preferably of the moving coil type; reversing key  $K$  (p. 585); switch  $S$ .

**Note.**—The ends  $H$  and  $E$  of the low resistance ( $r$ ) to be tested will of course be the terminals of the transformer coil, the ends of the cable or the brushes of the machine, the field coils being disconnected temporarily. The length of lead between  $D$  and  $H$  in the Fig. is immaterial.

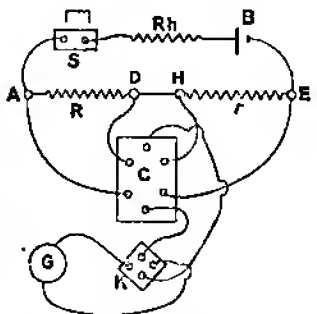


FIG. 34.

**Observations.**—(1) Connect up as indicated in Fig. 34, and adjust the galvanometer or voltmeter needle to zero. Clean the collecting arrangement at the part where the brushes press with fine emery cloth, assuming, for example, we are dealing with a dynamo or motor. To prevent the armature rotating, see that the *field circuit switch* is open, and that the brushes press on opposite ends of a diameter in the case of a direct current commutator.

(2) With  $R_h$  full in, close  $S$ , and adjust the current to give about quarter-scale deflection with the largest resistance of the

two, for then the deflection with the other is bound to be on the scale; then note the galvanometer deflection on each side of zero by turning  $K$ , when  $G$  is across each resistance in turn.

N.B.—The resistance  $R$  should be sufficiently high to prevent the current strength altering during any one pair of observations, and to prevent this current being strong enough to sensibly warm the resistances. The more sensitive the galvanometer the smaller this will be. After taking deflections with the second resistance, it is advisable to retake those with the first in case the current has altered. If they are not the same, take the mean of those on the respective sides of zero. For very accurate work a reversing key should be used with  $B$  to eliminate any thermocurrent effects.

(3) Repeat 2 for half, three-quarter, and full scale deflections, and calculate the unknown resistance  $r$  from the formula—

$$R + r = d_h + d_r$$

Tabulate as follows—

Name . . . . . Date . . . . .  
 Low Resistance tested . . . . . Standard low Resistance . . . . . Ohms

Deflection across $R$ .			Deflection across $r$ .			Ratio, $\frac{d_r}{d_h}$ $\frac{r}{R}$	Unknown, $r$ ohms = $R \frac{d_r}{d_h}$
Right.	Left.	Mean $d_h$	Right.	Left.	Mean $d_r$		

**Inferences.**—Prove the formula given in 3, and state any assumptions made in deducing it. What sources of error is the method liable to? How can they be minimized?

### (36) Measurement of Low Resistances by Voltmeter and Ammeter Method.

**Introduction.**—The following method, applicable to the measurement of the low resistances met with in the armatures of dynamos, motors, transformer coils and electric cables, is one of the simplest and a direct application of Ohm's law. It is not usually susceptible of the accuracy obtainable by the last method (Test No. 35) and depends on the accuracy of the ammeter and voltmeter used, and on that of observation.

**Apparatus.**—Low resistance ( $r$ ) to be tested; accurate ammeter ( $A$ ) and low reading voltmeter ( $V$ ), both preferably of the moving coil type; switch  $S$ ; variable current rheostat ( $R$ ), the form of which will depend on the current supply ( $E$ ) available. If  $E$  comprises two or three large secondary cells, then  $R$  may be a carbon rheostat (p. 597), but if  $E$  should be a 100 volt supply, then  $R$  may be a bank of lamps (p. 598).

**Observations.**—(1) If, as is indicated, an armature resistance is to be measured, connect up as indicated in Fig. 35. Adjust

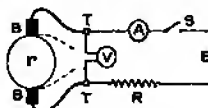


FIG. 35.

the pointers of  $A$  and  $V$  to zero, and see that the *field circuit of the machine is kept open* throughout the whole test by keeping the field switch open or otherwise.

(2) With  $V$  connected to the terminals  $TT'$  of the machine, as actually shown, and with ( $R$ ) *full in*, close  $S$  and take simultaneous ascending and descending readings on  $V$  and  $A$  for some five or six currents on  $A$ , differing in strength by about equal amounts between 0 and full-load armature current by suitably varying  $R$ —*the armature being at rest all the time*.

**Note.**—This measurement will give the Static “brush contact” resistance + resistances of armature and both brush leads  $BT$ .

(3) Repeat (2) with the armature rotating (*by hand*) while taking readings.

(4) Repeat (2) with the armature at rest, but with the ends of the voltmeter wires disconnected from  $TT'$  and carefully inserted under the brushes  $BB'$ , so as to press against the proper commutator segments, the straight ends of the wires so inserted being parallel to the length of segment. Tabulate all your results as follows—

Name . . .

Date . . .

Nature and Rating of Low Resistance tested . . .

$V$ connected to	Actual Resistance being tested	Amps $A$	Volts $V$	Resistance ( $V$ ) $\div$ $A$	Mean Resistance

(5) Plot, on the same axes, curves having values of  $V$  as ordinates, and  $(A)$  as abscissae for tests 2, 3 and 4.

**Inferences.**—What can be deduced from the curves and values of  $(\rho)$  obtained?

### (37) Measurement of the Armature Resistance of Machines and other Low Resistances by simple Potentiometer Method.

**Introduction.**—Since by Ohm's Law  $V = IR$ , where  $V$  = the P.D. across the ends of a resistance  $R$  carrying a current  $I$ , it follows that when the same current  $I$  flows through two resistances, the P.D. ( $V$ ) across each is  $\propto$  to that resistance. The previous test (No. 35) was based on this fact, but since actual deflections ( $\propto$  to the P.D.s) had to be compared, the accuracy depended to some extent on the current-deflection law of the instrument used, and on the instrument having a high resistance relatively to those measured. The present test, based on the Clark-Poggendorff method of comparing two E.M.F.s, and unlike the deflection method No. 35, is a null or zero method or one in which no deflection is the condition to be obtained. Hence the law of the instrument is immaterial, and an increase in its sensibility increases the accuracy of the test. Since also in this method the E.M.F.s to be compared are in turn placed in series with the instrument, the contact resistances of the connection to these E.M.F.s, as also the resistances of the connections, are immaterial; hence the greater accuracy with such a null method. Test No. 39 employs precisely the same principle as, but is a greater elaboration of, and a little more accurate than, the present method, in which we shall use a single or multiple metre bridge having a stretched undamaged wire of high resistance material, of uniform cross sectional area and size, and which will not sag due to heating by the current from one secondary cell connected direct to its extremities. Thus the E.M.F.s to be compared can be balanced against the uniform fall of potential along the wire due to a constant current flowing through it, and the ratio of the lengths so balanced will be that of the E.M.F.s across them.

**Apparatus.**—Armature  $A$  to be tested; known standard low resistance  $R$ ; switch  $S$ ; variable rheostat  $r$ ; secondary coils  $B$  and  $E$ ; Pohl's commutator or change over key  $C$ ; metre bridge  $PQ$  with sliding contact key; sensitive galvanometer  $G$ .

**Observations.**—(1) Connect up as shown in Fig. 36 and adjust  $G$  to about zero. Ensure the connections being such that when  $C$  is turned so as to include the fall of potential of either  $R$  or  $A$  in the circuit of  $G$ , each P.D. opposes that along  $PQ$  due to  $E$ .

(2) With  $r$  full in, close  $S$ , and adjust  $r$  so that with  $C$  turned to the larger of the two resistances, a position, say,  $L_A$  cms. from  $P$ , is obtained at which there is no deflection on  $G$ .

(3) Now quickly turn  $C$  to  $R$  finding some position  $L_R$  cms. from  $P$  at which  $G$  does not deflect; next, again verify whether the point  $L_A$  still gives balance. If slightly different take the mean of the new position and that in obs. 2.

(4) Obtain several pairs of positions such as  $L_A$  and  $L_R$  by altering ( $r$ ) and tabulate as follows—

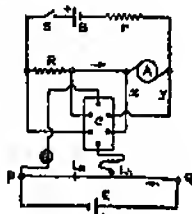


FIG. 36.

Name . . .				Date . . .	
Nature of unknown Resistance . . .				Galv No. . .	
Value of known Resistance $R =$ . . . Ohms.					
Wires or connections to which points of $t$	Unknown Resistance measured, Hot or Cold.	Distance of Slider from $P$ .		Unknown Resistance $R_A = \frac{L_A}{L_R} \times R$ .	Mean value of $R_A$ obsns.
		$L_A$	$L_R$		

**Inferences.**—On what does the accuracy of the test depend, and how can it be made more sensitive?

### (33) Measurement of Metallic or Conductor Resistance by the Silvertown Portable Testing Set.

**Introduction.**—The method used in measuring the resistance of the conductor of the circuit under examination is that of Wheatstone's Bridge.

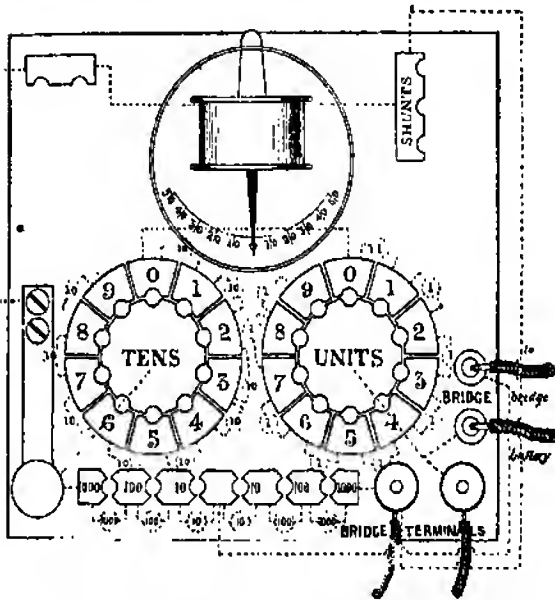
Fig. 37 below shows only those parts of the instrument which are employed in this test, and omits the parts and their connections which relate only to insulation testing. The parts employed are the following—

1. The adjustable resistance. This it will be seen consists of two sets of 9 coils, each connected to circular plug commutators or dials. One set of coils has nine resistances of ten ohms each, making ninety ohms in all, the other has nine resistances of one ohm each, making nine ohms in all. If the hole marked with any number, say 5, is plugged in the ten-ohm dial, a resistance of fifty ohms is inserted between the connecting leads entering and leading away from the dial; and a similar rule applies to the one-ohm dial. Hence if the hole 6 be plugged in the tens dial and the hole 8 be plugged in the units dial, a total resistance is inserted in the two in series of 68 ohms. The lowest resistance that can be obtained is given when both the 0 holes are plugged, when the coil resistance inserted is zero. The highest resistance is obtained by plugging the two 9 holes when the total resistance is 99 ohms. If no plug is inserted in one or both dials, the circuit is broken and the resistance is infinity.

2. The second part of the apparatus is the double set of proportional resistances, consisting of two coils of 10 ohms each, two of 100 ohms and two of 1000 ohms. Of these only one on each side of the centre is to be unplugged for any given test, and a rule is given later on for selecting the resistances to be employed to obtain the greatest possible sensitiveness; that is to say, for selecting those coils which will give the largest deflection on the galvanometer, when the resistance plugged in the dials varies by a given error from that of the circuit under test.

3. The third part is the galvanometer. Its two terminals are connected to the two ends of the Wheatstone Bridge by depressing

the contact key. It will be noticed that the shunt coils, with their plug commutator, are omitted from the diagram. This is done because they are not essential to the test, though they may be conveniently used when the balance of the bridge is not



*To the ends of the Conductor.*

**Connections for Testing Conductor Resistance.**

**FIG. 37.**

yet approximately correct, and very large deflections are being obtained.

4. The battery may consist of three Leclanché cells, having an electro-motive force of about 5 volts. One pole of the battery is connected in the usual way to the middle of the Wheatstone



Bridge, and the other to the point where the end of the adjustable dial coils is connected to one of the terminals, to which the conductor under test is attached. The connections are made by inserting the plugs at the end of the battery leads, in the two holes marked BRIDGE, and immediately this is done the current is established in the coils; the galvanometer circuit is of course not completed till the key is depressed.

5. The ends of the conductor to be tested are to be secured under the two terminals marked BRIDGE TERMINALS, and in measuring low resistances care must be taken that they are very securely attached. This may be done for very large or stranded conductors, either by soldering to their ends thin brass plates with holes in them of a suitable size to go under the heads of the terminals, or the connection may be made by means of finer wires soldered to the end of the main conductor. The resistance of these must be independently ascertained and subtracted from the gross result.

Providing an idea is first obtained as to the magnitude of the resistance to be measured, the following table will be found helpful in expediting any test with the "set."

TABLE III.

For Resistances tested between	Values of Proportional Arms		No. of Significant Figures in Result	Battery Power.	Remarks.
	Left-hand Coil.	Right-hand Coil.			
1 and 10	100	10	2	Ordinary	
10 and 100	100	100	"	"	
100 and 1000	100	1000	"	"	
1000 and 10,000	10	1000	"	Increased	An extra significant figure can be obtained, calculated by proportion from the deflection.
0.1 and 1	100	10	"	"	
0.1 and 1	1000	10	"	"	
0.01 and 0.1	1000	10	1	"	

A third figure can always be found in measuring resistances between one ohm and 1000 ohms, by observing the deflections of the galvanometer needles on both sides of the zero for different adjustments of the dial resistances near the balancing point.

For example, we will suppose that the 10-ohm coil in the right-hand side of the bridge, and the 100-ohm coil on the left-hand side are unplugged, and that when 45 ohms are plugged in the dial, and the key depressed, a throw of three divisions of the

galvanometer needle is observed to the right; and when 46 ohms are plugged we get a throw of two divisions to the left on the galvanometer scale. It is clear that the resistance to be measured lies between 4.5 and 4.6, and is nearer to 4.6 than 4.5, as two is less than three; that is, the resistance is 4.58 ohms. As a further example, suppose 100 ohms to be unplugged on each side of the bridge, and 82 ohms to be plugged in the dials; on depressing the key, no deflection of the needle is observed. On plugging 81 ohms in the dials, a throw of six divisions to the right is obtained, and on plugging 83 ohms we get the same deflection to the left. We are then amply justified in putting the third figure in the result as 0, and the resistance to be measured is 82.0 ohms.

Except in testing at the extreme range of the instrument, *i. e.* quantities less than one ohm or greater than 1000 ohms, the galvanometer will be found amply sensitive, and it is better to place the south end of the controlling magnet uppermost, thereby reducing the time of the oscillations of the galvanometer needle.

The battery should be in circuit as short a time as possible to avoid running down the cells, and it is well to take out one of the battery lead plugs when any alterations are being made in the plug commutators, only replacing it just before pressing the galvanometer key.

**Observations.**—(1) Connect up as indicated in Fig. 37, using the "set" precisely as there indicated. The box should be placed on a table, or some other approximately level surface in front of the operator, he facing the magnetic east, and the controlling magnet being in a vertical position. The pointer of the galvanometer will then be found to be swinging near its zero, and may be brought exactly to it by slightly turning the controlling magnet.

(2) Find roughly the resistance to be measured by unplugging ten in each of the proportional arms, and then adjusting the dial resistance so as to give a minimum deflection on pressing the key, the dial readings will roughly be the value of the unknown.

(3) Now proceed to balance according to the foregoing table and remarks, and tabulate as follows—

NAME . . .

DATE . . .

Resistance tested . . .  
Length of Conductor = . . .Temperature . . .  
Gauge = . . .

Proportional Arms.			Deflections to the				Calculated Resistance to balance $r$ .	Corrected dial $r_3 \pm r$ .	Unknown Resistance $= r_3(r_3 + r)$ .
Left $r_1$	Right $r_2$	Adjustable dial $r_3$	Right $d_1$	with $r_3'$	Left $d_2$	with $r_3''$			

N.B.—The resistance ( $r$ ), needed to exactly balance, is calculated thus—Assuming  $r_3'$  to be greater than  $r_3''$ , then  $(r_3' - r_3'')$  ohms corresponds to a deflection of  $(d_1 + d_2)$  scale divisions, and  $d_2$  corresponds to a resistance of

$$(r_3' - r_3'') \frac{d_2}{d_1 + d_2} \text{ ohms} = r,$$

$\therefore$  the correct dial resistance requisite to give no deflection

$$= r_3 + r = r_3 + (r_3' - r_3'') \frac{d_2}{d_1 + d_2} \text{ ohms.}$$

### (39) Comparison of Resistances. (Crompton Potentiometer Method.)

**Introduction.**—This method is a valuable one for comparing two or more resistances of almost any value, within reasonable limits, and consequently of determining the actual resistance in ohms of one of them, the other being an accurately known standard, such as one of the forms described on p. 605, which are some of the accessories of the potentiometer. The method, which is very simple and susceptible of great accuracy, is more particularly applicable to low resistances such as short lengths of electric light cables and the armatures of dynamos, etc., rather than multiples of the ohm, and it can be worked in such a way that the unknown resistance can be read off by inspection directly in ohms. Thus it will be seen that the present measurement is a practical development of that known as "Measurement of Low Resistance by the Fall of Potential Method," given on p. 84, and is a direct application of Ohm's Law. The principle of it consists in comparing the relative falls of potential down the two resistances traversed by the same current through the

medium of the potentiometer, employing the principle of the Clark-Poggendorff method for comparing two or more E.M.F.s. The Crompton potentiometer is a specially arranged form of comparing instrument, and the operator should, prior to commencing the test, make himself acquainted with the instrument, a detailed description of which is given on p. 510, together with the method of using it. The accuracy of the results is principally dependent on the standard known resistance, and the value of the largest current sent through this and the unknown must be such that the fall of potential down either does not exceed 1.5 volts, and that neither is warmed up by that current sufficiently to alter their resistances.

The observations may be taken in one of two ways—

(a) Suppose the potentiometer has been "set" by the Clark cell in the usual way (p. 514) for E.M.F. or current measurements, and that the standard resistance  $R_s = 0.01$  ohm. Then to avoid disturbing the "setting," balance each fall of potential down the two resistances, against that down the potentiometer, and compare the two P.D.s from the relation—

$$V_s : V_x = R_s : R_x$$

**Example.**—Let the standard balance with  $E$  on stud 1 and  $C$  at 95 on the scale, the P.D. across  $R_s$  is  $1000 + 95 = 1095$  volts. If now the unknown balances with  $E$  on stud 2 and  $C$  at 190 on the scale, the P.D. across it =  $2000 + 190 = 2190$  volts,

$$\therefore R_x = \frac{V R_s}{V_s} = \frac{2190}{1095} \times 0.01 = 0.02 \text{ ohms.}$$

(b) Suppose the potentiometer has not been "set" by the Clark cell. Balance up on the standard resistance instead. Thus put  $E$  to stud 1 and  $C$  at 0 on the scale, and alter  $G$  and  $G_1$  as described on p. 514, so as to "balance the potentiometer" for no deflection. Now with  $G$  and  $G_1$  fixed, balance with the unknown resistance, which position of balance will give the resistance  $R_x$  in ohms directly. In the present instance this would be  $E$  on 2, or  $R_x = 2 \times 0.01 = 0.02$ .

**Apparatus.**—Crompton potentiometer  $P$  (Fig. 208); secondary battery  $B$  capable of easily giving the largest current suitable for sending through the low resistances; switch  $S$ ; one secondary cell ( $b$ ) for the "working cell" of the potentiometer; accurately known low resistance  $R$  (p. 606); unknown low resistance  $r$  to be

tested; standard Clark cell  $E$ ; carbon rheostat ( $rh$ ) (p. 597); sensitive aperiodic D'Arsonval or moving coil galvanometer ( $g$ ) (p. 569).

**Observations.**—(1) As a precaution first place the levers of  $G$  and  $E$  (Fig. 206) on studs 14, and that of  $H$  on stud 1, then connect up as in Fig. 38, in which only the row of terminals on the potentiometer  $PP$  is shown symbolically.

(2) Adjust the galvanometer ( $g$ ) and current indicator  $A$  to zero (roughly), levelling them if necessary,  $A$  being merely for the

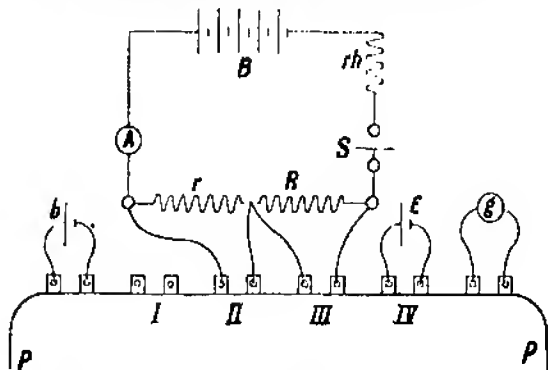


FIG. 38.

purpose of indicating roughly about what current flows in  $r$  and  $R$ . See that the standard resistance  $R$  chosen is of such a value as to be about the same as the estimated value of the unknown  $r$ .

**Note.**—The maximum current then to be used must not produce a fall of potential in either  $R$  or  $r$  exceeding 1.5 volts.

(3) "Set the potentiometer" as indicated in either  $\alpha$ , or balance on the standard resistance as in  $\beta$  above, the contact lever  $H$  referred to above being on studs  $IV$  or  $III$  respectively, as the case may be, thus inserting  $R$  or the P.D. across  $R$  in the circuit of ( $g$ ), and taking care that it opposes the P.D. due to ( $b$ ). Now close  $S$ , and adjust ( $rh$ ) so as to obtain some convenient current on  $A$ . N.B. This last-named operation is done before balancing  $P$  by method  $\beta$ .

(4) With the positions of the resistances  $G$  and  $G_1$  (Fig. 207, p. 510) as found in 3, unaltered, turn  $H$  to studs  $II$  or  $III$ , according to the "setting" employed, so as to throw into circuit with ( $\beta$ ) the P.D. across one or other of these terminals. Then adjust  $R$  and the slider  $C$  to obtain no deflection on ( $\rho$ ) when the latter is pressed, and note the reading of each.

**Notes.**—If it is impossible to "balance" owing to the spot of light being deflected always to one side, the P.D. down the resistance is assisting instead of opposing (as it should be) the fall due to ( $\delta$ ) in the stretched wire; the wires from resistance to potentiometer are then to be interchanged. Lastly, turn  $H$  again to the setting used in obs. 3 to see if balance is still obtained. If it is not, re-set  $P$  and repeat.

(5) Repeat 4 with  $H$  on the studs leading to the other resistance, if "setting  $\alpha$ " is the one being used.

(6) Repeat 3-5, obtaining some six or eight distinct sets of readings by suitably altering the current through  $R$  and  $r$ , and tabulate your results as follows—

Clark Cell: No. . . . . Temperature = . . . °C. E.M.F. assumed = . . . Volts.  
Potentiometer setting:  $R$  on . . .  $C$  at . . . Standard known resistance  $R_s$  = . . . Ohms.

Ammeter reading for reference only $A$	Potentiometer reading.						Unknown resistance $r = \frac{V_r}{V_s} R$ ohms.	Mean $r$ ohms.
	$R$ in circuit.			$r$ in circuit.				
	Stud of $R$ .	Slider $C$ .	P.D. $V_R$ .	Stud of $r$ .	Slider $C$ .	P.D. $V_r$ .		

**Inferences.**—On what does the accuracy of the test depend?

#### (40) Measurement of Low Resistance by the Nalder Low Resistance Measurer.

This method has the advantage of being a null or zero one, and entails the use of a specially arranged piece of apparatus or "measurer," together with a secondary cell capable of giving a current of 5 amps and a variable rheostat to adjust this current.

The general arrangement (Fig. 214) and method of use is given on p. 521, and will not be repeated here.

## Insulation Resistance.

**Introduction.**—Probably we shall not be straying very far from the truth when we remark that *Insulation Resistance* is one of the most important matters that an electrical engineer has to deal with. In fact, so obvious is this that the statement hardly needs qualifying; suffice it to say that a breakdown of the insulation resistance—whether of street main, appliance fed from it, or of an ordinary electrical installation supplied off it, will either cause a temporary or prolonged stoppage of the supply owing to the mere “blowing” of a protecting fuse or cut-out, or, if the circuit is over-fused, in the burning out of part of the circuit and possibly the firing of premises in which the breakdown occurs.

It is therefore of the utmost importance to be able to test the insulation resistance of a length of cable, main, or circuit, either when no current is flowing through it or when the supply is in actual progress and the main or circuit “*alive*,” as it is usually termed.

A number of different methods have been devised and are in general use for measuring the insulation resistance of both “*dead*” and “*live*” cables and systems, and in the following pages devoted to this question some of the principal and common ones in use will be considered. Before, however, proceeding with actual methods of measurement it may be profitable to make some general remarks.

Electrical cables and wires are in the first place tested for their insulating qualities by the manufacturer prior to being sent out to the purchaser, but the latter should test them also himself, both *before* and *after* laying, to make sure that no faults have developed, and of course periodically during use. Such a mode of procedure is of the utmost importance if efficient working and maintenance is to be obtained, for it is quite possible for a cable to be accidentally damaged during laying and a subsequent fault to develop at this point, due to the strain of working conditions, which will finally break down the cable.

### (41) Measurement of the Insulation Resistance of Electric Light Cables by the Direct Deflection Method.

**Introduction.**—The ordinary Post Office form of Wheatstone Bridge will measure resistances up to 1·111 megohms, though even at this maximum limit the measurements are not very accurate, owing to the resistances of the arms of the bridge being so widely different from one another; consequently it is unsuitable for measuring insulation resistance, which almost invariably amounts to much higher values, often of the order of hundreds of megohms. The present method of *direct deflections*, which is also termed the “simple substitution” method, is the most accurate in such cases and often the most convenient one to employ. The principle of it consists in comparing the deflection of a galvanometer needle caused by a given E.M.F. through a known standard high resistance in series with the galvanometer, with the deflection produced by the same E.M.F. working through the insulation of the cable to be tested substituted for the standard resistance.

**Preparation of Cable for Test.**—This must be carefully done and is of the *utmost* importance if the true insulation resistance of the dielectric is to be found, as the difference between the results obtained with properly and improperly prepared ends is very great. The method of doing this should be as follows—

(a) For vulcanized india-rubber cables, the braiding, tapes, or other covering should be removed for at least six inches from each end down to the surface of rubber covering, care being taken in doing this not to cut or otherwise injure the rubber covering still left.

(b) Wash this rubber surface with naphtha and scrape with a clean knife to remove any foreign material still left on the surface, and in this way so get a clean, fresh surface.

(c) Taper the rubber with a clean sharp knife for about 1" to 2" from the end, and then carefully dry the whole of the prepared end over a spirit flame *without burning the rubber*.

(d) Paint or coat the whole of the prepared end with three or four coatings, one after another, of clean paraffin wax, melted to a temperature *not exceeding* that of boiling water. This can be



done by placing the can of wax inside one of boiling water, whereas, if the wax is melted over a flame, it may be allowed to burn, and its insulating properties partially destroyed. As each coating of wax will have set before another can be put on, the whole cable end will be eventually sealed by a considerable thickness of the wax, which being much less hygroscopic than rubber, will not allow moisture to accumulate and so impair the prepared end. In lieu of wax the prepared end may be lapped with pure clean warm rubber tape well stretched, but this is not so good as the wax finishing.

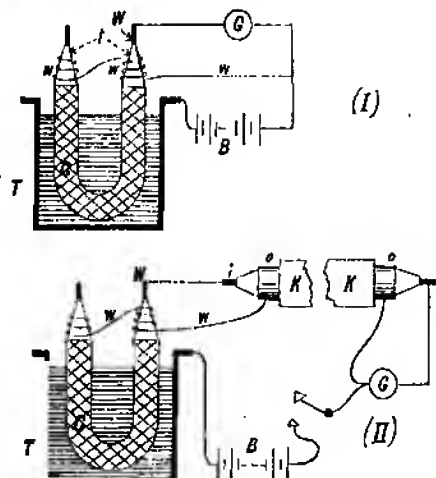


FIG. 89.

A better and much more expeditious way of eliminating errors due to surface leakage over the ends of a cable which is being tested for insulation resistance, than that just described of carefully tapering the ends and coating them with paraffin wax, is to employ an ingenious device known as Price's *guard-wire*. This, when properly applied, gives complete protection from errors due to end leakage in the *direct deflection* method, where the cable

ends are close to the galvanometer, and, consequently, the connecting wire between cable core and galvanometer is air insulated.

In the case of other methods, such as the *loss of charge* test, extra precautions are necessary to avoid errors (vide *Phil. Mag.* vol. xlix pp. 343-7, April 1900).

If the cable ends are close to the galvanometer then Price's guard-wire device in its simplest form is shown in Fig. 39 (*f*). *T* is a lead-lined tank of water in which the cable *C* to be tested, for insulation resistance, is immersed. The ends of *C* are prepared with a long clean taper (*t*) from the core *W*, so as to give a *long clean surface* of insulation exposed to leakage. A thin copper guard-wire (*w*) is wound two or three times round the tapered part rather nearer the outer braiding than the core *W* and connected as shown to the galvanometer *G* and high voltage battery

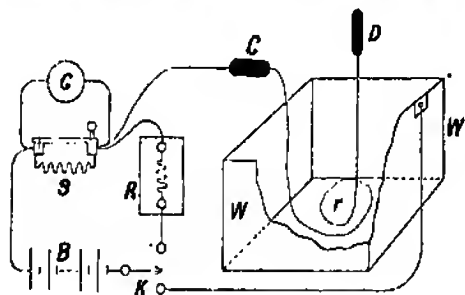


FIG. 40.

*B.* If now the resistances of the taper surface (*t*) are large compared with that of *G* they will all be at the same potential, and we shall have no leakage, but if any leakage exists (*w*) will tend to keep up the potential of *W*, the deflection of the galvanometer *G* being now reduced in the ratio  $\frac{a}{a+b}$ , where *a* and *b* represent the conductivities of *G* and *t* respectively. Consequently the correct result will be  $\frac{a+b}{a} \times \text{deflection}$ .

It will, however, be evident that in some cases the cable ends

cannot be brought up close enough to the galvanometer in order to have an *air insulated* wire connecting *G* and *W*.

The simplest and best way of getting over this difficulty is that suggested by Prof. Ayrton and Mr. T. Mather and represented in Fig. 39 (II). The inner conductor (*iv*) of a concentric wire (*K*) is used to connect *W* and *G*, the outer (*oo*) connecting (*W*) with junction of *G* and *B* as before. Now if *oo* has a high insulation resistance compared with the internal resistance of the testing battery *B*, complete protection is afforded against surface leakage, even though *KK* is lying on the ground.

**Apparatus.**—Sensitive high resistance Thomson astatic reflecting galvanometer *G* with its box of shunts<sup>1</sup> *S*; known standard high resistance *R*; unknown insulation resistance (*r*) of cable to be tested; well-insulated battery *B* of either Leclanché or secondary cells capable of giving an E.M.F. of from 100 to 500 volts; two-way highly insulated spring tapping key *K* (p. 586); suitable lead-lined water-tank *W*. If the "lead" or cable to be tested is small enough, it may be run direct from the key *K* into the water-tank *W* (clear of everything) and coiled up under water, the *free end* being carefully *kept dry* and left standing upright, about 12" out of the water, as indicated at *D*.

The tank should contain ordinary cold tap-water at a temperature of about 70° F., and the cable to be tested should be allowed to soak in this for 24 hours before the test, with its end trained up in mid-air above the water some 12" or so.

If the cable is too large to be taken up to *G*, a short well-insulated G.P. covered wire must be tied on to it at *C*, and the joint insulated as at *D*. In all insulation tests at least the working pressure which the cable is to be subject to should be used to test it with.

The known standard high resistance may preferably consist of a metal megohm, but in lieu of this costly piece of apparatus, a carbon megohm, checked against a metal 100,000 ohm coil occasionally, will do quite well, and costs only a few pounds. It must, however, be borne in mind that such a resistance slowly alters its value with time and temperature, so that the temperature should be noted each time it is checked by the present method.

**Note.**—To avoid damaging the galvanometer, which is a very

<sup>1</sup> Or the Ayrton and Mather Universal Shunt-box.

delicate one, the shunt-box provided with it must always be used in the way indicated below.

**Tests.**—(1) *With the lever switch or short circuit bar of  $S$  down, thus short circuiting the galvanometer terminals, and also with the shunt-plug in the  $\frac{1}{100}$  hole, connect  $S$  up to  $G$  first, and then the rest of the circuit as indicated in Fig. 40, and adjust the spot of light to zero by means of the controlling magnet.*

(2) Remove the short circuit in  $S$ , and, with the  $\frac{1}{100}$  shunt plugged up, gently tap  $K$  for a fraction of a second so as to complete circuit through the standard known resistance  $R$ ; if the deflection is inappreciable, release  $K$  to plug up the  $\frac{1}{10}$  shunt, and again tap as before, and so on until a convenient steady deflection  $d_s$  is obtained. Note this and the shunt  $S_A$  in use at the time (if any).

**N.B.**—*The key  $K$  must always be released before altering the shunt  $S$ .*

(3) See that the short circuit lever of  $S$  is down so as to short circuit the galvanometer terminals, and that the  $\frac{1}{100}$  shunt is in. Now close  $K$  through the insulation resistance, and after about half-a-minute open the short circuit switch.

**Note.**—If this method of procedure is not followed a sudden ballistic rush of current may ensue through  $G$ , just at first, from the high battery E.M.F., into the cable, owing to this latter acting as a capacity, i. e. condenser, and thus damage the galvanometer. At the end of one minute note the steady deflection  $d_r$ , and with the key  $K$  still closed, again at the end of every minute up to between five or ten, say.

If without the wire connecting  $K$  and  $W$  there is leakage from battery and galvanometer which gives a deflection  $d_w$ . Then  $(d_r + d_w)$  or  $(d_r - d_w)$  must be used instead of  $d_r$  simply, according as to whether  $d_w$  is opposite or in the same direction as  $d_r$  respectively.

(4) Repeat 2 and 3 for about 3 or 4 pairs of deflections if possible in different parts of the scale, with  $R$  and  $r$ , by altering  $S$ , and calculate the insulation resistance ( $r$ ) from the formula below, and tabulate as follows—

NAME . . . . . DATE . . . . .  
 Coils.—Insulating material = . . . . Resistance of Galvanometer  $G$  = . . . ohms @ . . . °C.  
 Size of copper core = . . . S. W. G. " Standard  $A$  = . . . " @ . . . °C.  
 Length immersed  $L$  = . . . Mils.  
 Time of immersion = . . . Hours. Temperature = . . .

E.M.F. used.	Standard Known Resistance.			Unknown Insulation Resistance.			
	In ohms $R$ .	Deflection $d_R$ .	Shunt $S_R$ .	Time in min. from closing $K$ .	Deflection $d_r$ .	Shunt $S_r$ .	Megohms per mile $r \times L$ .

(5) Plot a curve between time of electrification in minutes as abscissae and corresponding deflections  $d_R$  as ordinates.

Note.—If  $S = \frac{1}{v}$  (say), then  $\frac{S}{S+G} = \frac{1}{v}$ , or  $\left(1 + \frac{G}{S}\right) = 10$ .

Inferences.—Prove the formula mentioned in 4, i. e.:

$$d_R \left[ R \left( 1 + \frac{G}{S_R} \right) + G \right] = d_r \left[ r \left( 1 + \frac{G}{S_r} \right) + G \right]$$

and state what assumptions are made in deducing it.

Should it be found impossible to keep the deflection on the scale with the standard known resistance in circuit and the  $\frac{1}{100}$ th shunt in, using the full battery E.M.F., then employ only a known fraction of this total E.M.F. (as measured by an electrostatic voltmeter) when taking a deflection  $d_R$  with the standard, whence in the above formula we must use  $\frac{V}{v} \times d_R$  instead of  $d_R$  simply where  $V$  = full E.M.F. and  $v$  that used to obtain  $d_R$ . In testing short lengths of highly insulated cable at the least an E.M.F. of 300 or 400 volts should be used.

Referring to the ten 1-minute readings of deflection in observation 3 above, the deflection will fall rapidly at first and then more slowly. This is not due to increase in the insulation resistance, as it might appear to be, but to dielectric absorption in the cable through this acting as a condenser.

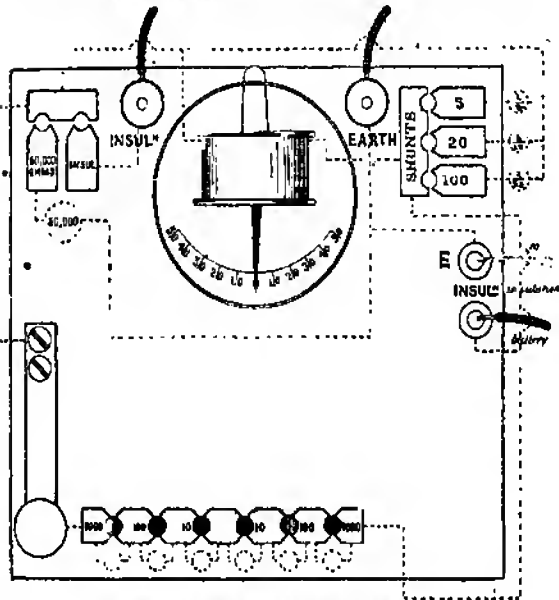
This particular test is a good one for developing a fault which would pass observation in a test of 1 minute's electrification, in which case there would either be an irregular—or no—crawling of the deflection in the 10 minutes.

Insulation resistance is usually specified in megohms per mile at 70° F. after 24 hours' immersion and 1 minute's electrification at some definite voltage.

It is necessary to record the temperature at the time of the test, as the insulation resistance decreases as temperature increases.

*To Conductor of Cable.*

*To Earth or Sheathing.*



### Connections for Testing Insulation Resistance.

FIG. 41.

### **(42) Measurement of Insulation Resistance by the Silvertown Portable Testing Set.**

This is a measurement of the electrical resistance of the insulating material of a cable to the passage of a current from the inside conductor through the insulation to the lead sheathing, wet yarn, armour, or other outside conducting surface, and the inverse of the insulation resistance is generally termed the leakage.

This measurement is effected by a method known as that of direct deflections. It consists in passing a current from a battery through a galvanometer into a conductor of a cable whose farther end is free and disconnected, thence through the insulating material to the outside coating or earth, and so back along a temporary conductor to the other end of the battery, the deflection of the galvanometer needle produced by this current being noted. Replacing that part of the circuit which was formed by the insulating material of the cable by a standard resistance of known value, we obtain a new deflection of the galvanometer needle.

The diagram Fig. 41 shows only those parts of the apparatus and their connections that are used in this measurement; those which relate only to the measurement of conductor resistances being omitted.

The arrangement, it will be seen, is as follows:—One pole of the battery—the battery of Leclanché cells giving an E.M.F. of about 100–200 volts is normally employed—is connected by a conductor, ending in an ebonite-headed plug, to the lower of the two plug-holes marked *INSUL*. Thence the current passes along a connecting wire to the block marked *SHUNTS*, and thence through the galvanometer to the upper block on the other side. We may observe in passing that these two main blocks, one on each side, are practically the terminals of the galvanometer. If a shunt is plugged,  $\frac{1}{4}$ th,  $\frac{1}{10}$ th, or  $\frac{1}{100}$ th only of the current passes through the galvanometer, the remainder finding its way through the corresponding shunt coil.

From the upper block on the left-hand side the current may take two paths, according as the hole marked *INSUL* or that marked 50,000 ohms is plugged; if neither is plugged, the circuit is broken, and no current can pass. This plug forms consequently a convenient make and break key. If the hole marked *INSUL* is plugged, the current passes to the terminal marked *INSUL*, so through the insulating covering of the cable to the outside sheathing or earth, back to the terminal marked *EARTH* and the plug-hole marked *E*, and then along the lead to the other pole of the battery. If, however, the hole marked 50,000 ohms be plugged, the current will pass through the coil of 50,000 ohms, then along a connecting wire to the plug-hole *R*, and so back to the battery.

In beginning this test the conductor of the cable, or insulated wire, or a temporary lead attached to it, is connected to the terminal of the instrument marked *INSUL*, and another lead, connected to the outside sheathing of the cable, or the wet soil in which it lies, is attached to the terminal marked *EARTH*, care being taken that these leads are separated, and that no circuit exists between them except through the insulation of the cable.

It will be observed that when all the holes in the straight commutator near the front of the box are plugged, the key on the left-hand side, which is used in the bridge test as a galvanometer make and break key, becomes for the insulation test a short circuit key, and is useful for checking quickly the oscillations of the needle.

*N.B.*—Although the maximum voltage of the testing battery usually employed with this testing set is only 100 volts, the set can be used with a testing voltage of 200 volts, as required by the Board of Trade regulations. In this case, instead of using the multiplying power of 20 as described above, the multiplying power of 100 should be used in taking the constant—the deflection thus obtained will be the same as that which would be given by the unshunted galvanometer through a total resistance of five megohms, and the calculation of the resistance to be measured would then be made in exactly the same manner as described above, except that five megohms will be substituted for one megohm.

In making this test the following points may be called attention to—

(1) Too much care cannot be taken in preparing the ends of the cable. Since we are measuring a very small current of electricity passing from the conductor to the outside sheathing, through the insulated covering, it is clear that our results will be entirely misleading if any current be allowed to pass over a dirty surface at the ends where the conductor is exposed. These ends should be looked to before testing, and in the case of india-rubber or other firm material, the section of the insulator should be pared all over with a sharp and perfectly clean knife. For methods of preparing the ends see pp. 99—100.

(2) Care should be taken not to short circuit the battery, which may easily occur in two ways. One is by allowing the two battery plugs to touch one another, when the other ends of the leads are



attached to the battery terminals; and another is by allowing the lead attached to the earth terminal to touch that attached to the insulation terminal.

In both cases the battery of small cells will be for a time much overworked, and in the second the needle may become bent or demagnetized.

(3) Another point that may be noticed is that in deducing the insulation resistance per statute mile from a test on any given length, the result obtained from a test on the latter is to be multiplied by the length of the piece in miles, and not divided by it.

For example, if the insulation of a cable three miles long be 15 megohms, the insulation per mile will be  $15 \times 3$  or 45 megohms; or again, if the insulation of a piece of cable, whose length is 350 yards, be 7520 megohms, the insulation per statute mile will be  $\frac{7520 \times \frac{1760}{1760}}{1760}$  megohms = 1496 megohms.

If the galvanometer deflections are proportional to the currents producing them, and the E.M.F. employed is constant throughout the whole test, then we have current  $\propto$  deflection  $\propto \frac{1}{\text{total resistance}}$ ; or if  $R_I$  = insulation resistance tested and  $d_I$  = deflection through it, and if  $R_S$  = standard known resistance and  $d_S$  = deflection through it, then

$$\frac{R_I}{R_S} = \frac{d_S}{d_I} \quad \text{whence } R_I = \frac{d_S}{d_I} R_S \text{ megohms,}$$

where  $R_S$  = the standard resistance in megohms.

If, however, the galvanometer is shunted with, say, a  $\frac{1}{5}$  shunt, for example (with the insulation), so that only  $\frac{1}{5}$  of the main current goes through it, then, since without the shunt the deflection would be five times as great, we have

$$R_I = \frac{d_S}{5d_I} R_S \text{ megohms.}$$

Thus, for example, suppose that a given battery produces on the needle of a galvanometer placed in series with the insulation of a cable in the manner described, a deflection of 10.3 divisions, and that on substituting a resistance of one megohm for the insulation we get 42 divisions, we find that the insulation resistance is  $\frac{42}{10.3} = 4.1$  megohms approximately.

Again, for example, suppose that the current from the battery

when passed through a constant resistance of 50,000 ohms gave a deflection of 42 divisions on a galvanometer shunted to  $\frac{1}{10}$ , and that when passed through the cable insulation it gave 23 divisions with the galvanometer shunted to  $\frac{1}{1}$ , the insulation resistance would be  $\frac{42}{23 \times 10}$  megohms = 37 megohms approximately.

In cable testing the battery employed should in all cases give an E.M.F. at least = the working voltage under which the cable works. The terminal marked EARTH on the right of the galvanometer must be connected to earth (i.e. nearest gas or water-pipe) or to the water of the tank if the cable is being tested in such.

Tests.—(1) Connect up precisely as in Fig. 41, and adjust the galvanometer needle to zero.

(2) Now take the "constant" of the galvanometer by plugging the 50,000 ohm hole and the  $\frac{1}{10}$  shunt and note the steady deflection  $d_2$ . This is the same deflection as that which would be obtained with the same E.M.F. through  $(50,000 \times 20) = 1,000,000$  ohms, or 1 megohm for no shunt at all.

(3) Plug up hole marked *INSUL.*, instead of that in 2, and adjust the shunts (if necessary at all) to obtain a steady deflection  $d_1$ , preferably as nearly = to  $d_2$  as possible.

(4) Calculate the insulation resistance from one or other of the preceding formulae and note for reference merely the E.M.F. used in the test.

N.B.—If the cable has been soaking in a water-tank note the time of immersion and the temperature of the water. Also the number of yards immersed.

## Insulation Resistance of Electric Light Street Mains and House Installations.

Introduction.—MAINS.—Seeing the extreme importance of maintaining continuously, and without any intermission of any kind, the supply of electrical energy from a central station when once commenced, it should be the endeavour of any engineer to obtain and lay the best possible class of cables in the most efficient, thorough, and lasting manner in his power. The item of mains in the supply of electrical energy is a very serious one

at the best, and usually amounts to something like from  $\frac{1}{3}$  to  $\frac{2}{3}$  of the cost of the whole undertaking.

Notwithstanding this, however, the best possible main only should be laid if the system is to be a lasting one, free from perpetual worry to the engineer, of cables breaking down and the consequent temporary discontinuity of the supply. The insulation, jointing, and laying should be the best it is possible to obtain, for even in localizing a fault the accuracy of the test will greatly depend on the goodness of the joints.

There are roughly speaking three tests, which should be carried out on any new cable or main, namely—

(a) The insulation and copper resistances of each cable drum as soon as it arrives from the manufacturers. This can only be done satisfactorily under a pressure of at least double that which the cable will work at in practice, and with the whole cable drum wholly immersed in water at about 70° F., the ends being carefully kept dry, trained out of the water and prepared in the manner described on p. 99. Reliable results cannot be obtained from a well-wetted drum, only from one wholly immersed for 24 hours.

The insulation resistance should be obtained by the "direct deflection" method after one minute's electrification (*i. e.* application of the battery), and again at the end of every succeeding minute for some ten minutes.

The first reading will give, or should give, at least, the specified insulation resistance of the maker.

The second and subsequent readings are extremely useful in showing the existence of undeveloped faults in the cable insulation, which would in the usual course of events pass the specification in the one-minute test unnoticed. Should the insulation be faulty, the galvanometer deflection will hardly fall at all after the first minute's electrification, or may fall in irregular jumps. The resistance of the copper core should be taken and noted down, as well as the length of the cable on the drum.

(b) The insulation and copper resistances during laying both before and after jointing in the following manner:—A careful test should be made on the first section of the line, one end of which we will assume is in the station when laid, but before any joint is made, and with both ends carefully prepared (*see* p. 99).

If satisfactory, it will show that no damage has been done to it in the laying operation.

The second section is then laid and carefully but temporarily is connected to the first section by a piece of lead. These two adjacent ends and the far end of section 2 are carefully prepared and the two sections tested. If the insulation resistance per mile<sup>1</sup> is up to specification, section 2 is all right and can be now jointed to 1 and the test repeated. If not the same as before the first joint is defective and should be re-made. Now lay section 3 and again test as before, and so on; thus, finally, the whole line will have been tested section by section as the laying proceeded, and, lastly, as a whole. In this way a record of all the tests will be to hand at any future date, while any damage done in laying, or any badly-made joint, will be at once detected by fall in the insulation resistance per mile, and a rise in the copper resistance per mile.

(c) Daily tests (while working or otherwise), the precise method of performing which will depend on whether the main is a high or low tension one.

A fault occurring should at once be localized and remedied. If on a "feeder" it can easily be found, but if on a distributing main, sectioning off may be necessary to localize it.

The apparatus requisite for these tests is the same as that enumerated on p. 101, and with which the testing-room of every station should be provided, in addition to other instruments.

The minimum insulation resistance for low tension cables at 100 volts is about 300 megohms per mile after 24 hours' immersion and one minute's electrification. In high tension cables at 2000 volts it is about 4000 megohms per mile under similar conditions.

**Ordinary Installations.**—Many of the preceding remarks apply here. For example, it is much more economical in the long run to wire a building with high-class insulated wires and leads as also with good fittings having fairly high insulation.

<sup>1</sup> The insulation resistance per mile = measured (total) resistance  $\times$  the length in miles tested. This arises from the fact that the leakage current through two miles is twice that through one mile, assuming, of course, that no appreciable fault exists anywhere along the length of cable.

The last-named condition to be aimed at is an important one when we consider that every lamp switched on brings one or more fittings, such as a lamp-holder, cut-out, switch, ceiling rose, etc., into active use, thereby adding so many additional parallel paths of surface leakage through which current can leak away to earth. This in other words means a diminution in the total insulation resistance of the whole installation, and which is considerably aggravated by damp weather, dust and dirt, etc. With respect to leakage of current, the rule given by the Institution of Electrical Engineers is that the total leakage should not exceed  $\frac{1}{1000}$ th part of the total working current. Numbers of different rules and regulations are given by the various Fire Insurance and Supply Companies. As an example of the latter we may cite the rules of the Edinburgh Corporation for installations tested at 115 volts with minimum insulation resistance.

TABLE IV.

For 12 lamps 5.0 megohms.				For 150 lamps 0.75 megohms.			
"	25	"	2.5	"	200	"	0.5
"	50	"	1.5	"	250	"	0.3
"	75	"	1.25	"	300	"	0.2
"	100	"	1.0				

The rules of the Leeds Corporation for 200 volt circuits are some 20% less than the above in the minimum insulation resistance for the same number of lamps in the respective cases.

Ordinary insulation resistance tests for installations must be taken with—*all fuses "in," all lamps removed* from their holders and *all switches "on,"* with at least the working pressure for which the installation is intended, but preferably double this. It is then advisable to make three tests as follows—

- (a) of the insulation resistance between +ve leads and earth,
- (b) " " " " " " -ve " " "
- (c) " " " " " " +ve and -ve leads.

The value in each case should not be less than that specified above or thereabouts for the particular number of lamps installed.

Usually the insulation resistance for alternating current circuits has to be greater than for direct currents, and in some regulations these are as 1:2.

The importance of testing at or even above the working pressure will be seen from the following figures by F. Uppen-

born of Berlin, which show in a marked degree the way in which the so-called insulation resistance varies with different voltages.

TABLE V.

Resistance between			
Terminals of slide cut-out.		Two twisted cotton covered wires.	
Volts.	Megohms.	Volts.	Megohms.
5	23	5	261
10	53	10	188
15.9	46	15.9	124
27.2	24	27.2	121

This drop in the reading of insulation resistance as the volts increase will generally be found to occur with, and is due to, moisture in or on the insulation under test. The increase of voltage may either break the insulation down, or the current, due to the voltage, may partially dry the moisture out and the reading gradually rise with the time of application.

Further, in measuring insulation resistance, sudden variations will sometimes be observed, especially will such be noticeable in direct reading testing sets. This is invariably due to metallic or other conducting particles on the surface (or, very rarely, buried in the insulation) promoting surface leakage, and the rapid fluctuations are due to intermittent sparking between such particles. Thus a direct reading testing set discriminates between low insulation due to damp, that due to dust, and that due to conducting particles, or whether the insulation is disintegrating under electric stress.

#### (43) Insulation Resistance of Electric Light Installations, Cables and Machinery by Evershed's Direct Reading Portable Testing Sets.

**Introduction.**—While there are several portable insulation testing sets on the market of both the direct and indirect reading types, we shall here consider the time-honoured form due to Mr. Sydney Evershed, which indicates the instantaneous insulation under high pressure by the direct deflection of a pointer on a scale. Thus the tests can be safely entrusted to

anyone possessing practically no technical skill who can make a report, and so enable defective work to be discovered before covering in.

The Evershed type is made by Messrs. Evershed and Vignoles, Ltd., in two forms, namely—

(1) *The "Megger" Insulation Testing Set*, which is the most modern development of the early form of Evershed ohmmeter and generator.

(2) *The "Bridge-Megger" Testing Set*, which combines the functions of the first-named "Megger" set with those of a Wheatstone Bridge.

Both sets consist of an ohmmeter of the moving coil type combined in one box with a hand-driven generator for providing the necessary testing pressure and current. When the handle of the generator is not being turned, the pointer is entirely free and will rest anywhere on the scale.

The internal construction and arrangement of the ohmmeter portion in both sets is the same, except for some minor additional details in the case of the Bridge-Megger set, which will be indicated later on.

We will therefore consider the use, firstly, of type (1) above, namely—

**The "Megger" Insulation Testing Set.**—The generator portion of this particular set may be either of the *variable pressure* or *constant pressure* kind. Unless the *electrostatic capacity* of the work to be tested exceeds one microfarad or so, a variable pressure instrument is suitable, which is the case for testing wiring, switch gear, dynamos and motors, arc lamps, instruments and accessories. Megger insulation testing sets being ohmmeters, their readings are independent of the applied pressure. If, however, the insulation under test has a large electrostatic capacity, the reading may become unsteady, due to the capacity current, caused by the variable pressure flowing through the current coil only; but even on large capacity, once the circuit is charged, the capacity current ceases and the reading becomes perfectly steady.

For work likely to have a capacity exceeding one microfarad or so, such as the wiring in metal conduits, lead-covered cable, underground mains and a modern system of house-wiring in

metal conduit, which has often a considerable capacity, the constant-pressure type of set should always be used.

The type of testing set now being considered is intended primarily for the measurement of insulation resistance, and is not available for metallic resistance tests. The low-range variable pressure sets are made in three ranges of 0-10, 0-20, and 0-100 megohms with 100, 250, and 500 volts respectively (at 100 revs. per min.), while the constant pressure low range

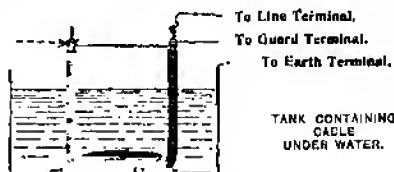


FIG. 42.

sets are made in the same three ranges together with a fourth for 0-200 megohms with 1000 volts. The high-range constant pressure sets are made in three ranges of 2-1000, 4-2000 and 4-5000 megohms with 500, 1000 and 1000 volts respectively. These last-named "Megger" Insulation Testing Sets are provided with a *guard wire* terminal, and, as explained on page 100, any error in tests of high insulation due to leakage internally or across the surface of the insulation under test can be eliminated, and hence the readings of the set remain unaffected, by tightly wrapping a so-called *bare guard wire* round the tapered insulation between conductor and earth, and connecting it to the guard wire terminal as shown in Fig. 42.

### To Measure Insulation Resistance by the "Megger" Insulation Set.

**Observations.**—(1) For both low-range-variable and-constant pressure sets, as well as for the high-range constant pressure set: place the instrument on a steady base, but not on the bedplate of, or very close to, a dynamo or motor.

(2) Connect the terminal marked **LINE** to the insulated copper



core of the appliance under test, and that marked **EARTH** to a good earth such as a water-pipe or earthplate; or for testing between, say, two insulated wires, connect one wire core to each terminal. Then—

(3) Turn the handle in a clockwise direction at a speed of at least 100 revs. per min., at which—

In variable-pressure sets, the generator will be giving its rated or normal voltage which can be increased by increase of speed, and—

In constant-pressure sets, the clutch is felt to be slipping (for at any speed above that necessary to give slipping, the voltage will be constant). Now read the insulation resistance as given by the deflection of the pointer on the scale.

(4) High-range constant pressure sets (in addition to obs. 1-3 above) must be *levelled* by means of the spirit-level seen through the hole in the dial, and the *index must be adjusted to infinity* before connections are made to any of the terminals, by rotating the handle above the clutch-slipping speed and turning the knob of the index adjuster one way or the other until the index stands exactly on the mark at infinity.

**Note.**—In testing circuits of considerable electrostatic capacity it is essential to maintain full speed for at least a minute before taking the reading. Further, to eliminate errors due to surface leakage, a guard wire (see p. 100) must be used.

## To Measure Insulation Resistance by the "Bridge-Megger" Testing Set.

**Observations.**—(1) Connect up, as in Fig. 43, and turn the change-over switch to "Megger," the instrument being on a steady base and not very close to a dynamo or motor.

**Note.**—In all cases the **LIVE** terminal must be connected to the insulated conductor of the circuit or appliance under test and the **EARTH** terminal to a good earth, such as a water-pipe or earthplate, or the equivalent. This with machines may be the framework, with conduit wiring should be the metal conduit itself, with lead-covered street main should be the lead sheathing, and for non-sheathed cable should be the water in the immersion tank, etc.

(2) The handle is then rotated clockwise just above the speed at which the clutch is felt to slip. This occurs at about 100 revs. per min., while at any higher speed the voltage is constant, and the insulation resistance is then read off by the deflection of the pointer on the scale.

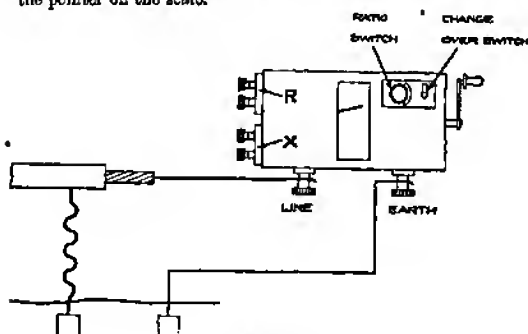


FIG. 43.

#### (44) To Measure Conductor Resistance by the "Bridge-Megger" Testing Set.

For use in this measurement, the adjustable standard known resistance box, supplied with this set, is required. Then to measure—

*Resistances under 100 ohms.*—(1) Stand the instrument on a steady base and with all terminals free from any outside connections. Adjust the pointer to "infinity" on the scale by turning the knob of the index adjuster one way or the other until the pointer or index stands exactly on the infinity mark.

(2) Connect up as in Fig. 44, set the change-over switch to "Bridge," the ratio switch to 10 or to 100, and all the resistance box dials to zero.

(3) Rotate the handle *slowly* clockwise with the right hand, when the pointer will float off the scale on the side marked "increase R" above the line marked G, simultaneously with the

left hand raising the value of  $R$  by turning the resistance box switches until the pointer exactly covers the line  $G$ .

(4) Now rotate at full speed to give maximum voltage and hence sensibility, readjusting the box resistance  $R$ , if necessary, to keep the pointer on the line  $G$ .

Then the resistance tested = the value of  $R \div 10$ , or by 100, whichever is in use.

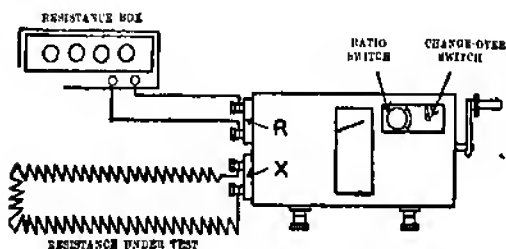


FIG. 44.

*Resistances from 100 to 9999 ohms.*—(5) Operate tests 1-4 above, except that in (2) the ratio switch is now set to 1 instead of to 10 or 100 as above. Then the resistance in the box required to balance the pointer exactly on the line  $G$  is now the value of that under test.

**Note.**—When measuring field coils of dynamos and motors, or other metallic resistances of large self induction, the generator must be driven above the speed at which the clutch slips to ensure the current being constant in the arms of the bridge.

*Resistances from 10,000 to 999,900 ohms (by "Bridge" method).*—(6) Operate test (1) above.

(7) Connect up as in Fig. 45, set the change-over switch to "Bridge," and the ratio switch now to 10 or to 100.

**Note.**—It will be observed that the connections of the unknown resistance and box to the testing set in Fig. 45 are just the reverse to those of Fig. 44.

(8) Operate tests (3 and 4) above, remembering that the directions "increase  $R$ " and "decrease  $R$ " are now also

reversed, and that the unknown resistance now = box reading to balance  $\times 10$  or  $100$ , whichever ratio is in use.

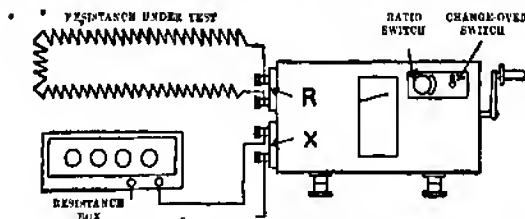


FIG. 45.

*Resistances from 10,000 ohms and upwards (by "Megger" method).—*This method is more rapid, but less accurate than the last, and is operated exactly as for Test No. 43, p. 115, the connections being as in Fig. 46.

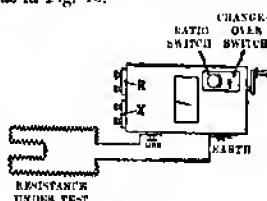


FIG. 46.

#### (45) Measurement of the Insulation Resistance of a Complete Electric Light Installation and plant *while working*.

**Introduction.**—The insulation resistance of any system of distribution of electrical energy when *not working* can be determined by one of the preceding methods. These are, however, inapplicable to systems actually running, and consequently "alive" at the full working pressure. It is most important to make frequent, if not daily, tests of the insulation resistance of any installation in order that a gradually developing fault, which

would cause the insulation resistance of the whole system to gradually fall, might be discovered in time and remedied before it perhaps burnt itself out and fired the premises.

The following method is a simple and convenient one for making such a test on any system, whether that of a country

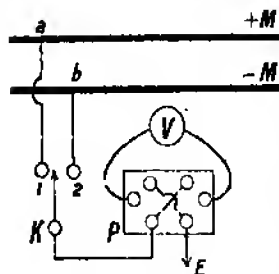


FIG. 47.

house, having its own generating plant or the main distributing network of a large town. The arrangement is shown in Fig. 47, where  $+M$  and  $-M$  are the positive and negative mains or wires of a two-wire system of direct current distribution.

The contact studs 1 and 2, of a two-way key  $K$  (p. 586), are electrically connected (temporarily or otherwise) to

any points  $a$  and  $b$  of these mains, which might be the  $+$  and  $-$  bus. bars on the switch-board. The common terminal of  $K$  is connected through a Poll's commutator (p. 584) or other reversing key  $P$  to earth  $E$  (i. e. nearest gas- or water-pipe). By means of  $P$ , a voltmeter ( $V$ ) connected to  $P$  has its terminals interchanged between  $K$  and  $E$  on moving  $P$  over so as to reverse. Thus a current flowing either from  $K$  to  $E$  or  $E$  to  $K$  can be made to give a deflection in the same direction on  $V$  by manipulating  $P$ . If this latter is used it can be converted into a reversing key by cross-connecting the four mercury cups, as shown by separate connectors indicated by the dotted lines; both  $K$  and  $P$  should have a good insulation resistance;  $V$  should be a  $+$  and  $-$  instrument, preferably of the moving coil D'Arsonval type. It may either be a voltmeter or ammeter, but we shall assume the former in the present case.

**Observations.**—(1) Connect up as shown and put  $K$  to stud 1,  $P$  being such as will allow  $V$  to deflect over the scale. Note the reading  $V_1$  on the voltmeter.

(2) Put  $K$  to 2 and reverse at  $P$  so as to still make  $V$  read on the scale. Note the reading  $V_2$ .

(3) Calculate the insulation resistance of the whole lighting system (including dynamo, battery, leads, cut-outs, lamps, etc., etc.) from the relation—

$$R = r, \left( \frac{V}{V_1 - V_2} - 1 \right) \text{ ohms;}$$

where  $r$  = the resistance in ohms of the voltmeter, and  $V$  = the working pressure at the time across  $+M$  and  $-M$ .

The insulation resistance of the  $+ \text{ main}$  is

$$R_1 = \frac{r, [V - (V_1 - V_2)]}{-V_2}$$

and of the  $- \text{ main}$  is

$$R_2 = \frac{r, [V - (V_1 - V_2)]}{V_1}.$$

Since  $V_1$  and  $V_2$  are to opposite sides of zero, or on the same side by reversing at  $P$ , they must be added;  $r$ , should not be too large, but its value depends on the insulation resistance tested. If this be 100 ohms or so,  $r$ , might be of the order of 1000 ohms. Since the value of  $R$ ,  $R_1$  and  $R_2$  in ordinary small installations is usually high, i.e. considerably over 1000 ohms, a voltmeter may be used having a resistance ( $r$ ), of, say, 5000 to 10,000 ohms.

**Inferences.**—Why is an electrostatic voltmeter unsuitable for use in the above test?

#### (46) Measurement of the Insulation Resistance of Complete Electrical Installations and Distributing systems while working.

**Introduction.**—The following method is one of the most accurate for measuring the insulation resistance of a system taken as a whole, but it does not give any idea as to which main a fault may be developing. It is really an application of Mance's method for determining the resistance of a conductor containing an E.M.F., and entails the use of preferably an ordinary Post Office pattern Wheatstone Bridge, with its detecting moving needle galvanometer  $G$  (p. 571) and an extra-resistance ( $r$ ) for safety. Fig. 48 shows the sketch of connections for the test, where  $+M$  and  $-M$  are the mains the insulation resistance  $R$  of which it is desired to measure;  $E$  represents earth (i.e. the nearest gas- or

water-pipe);  $FF$  are protecting fuses. The P.O. Bridge is represented symbolically by the zigzag lines  $A, C, S, D$ , which indicate the rows of plugged resistance coils.

**Observations.**—(1) Connect up as shown, joining the bridge terminal  $D$  to some point ( $a$ ) on the distributing system to be

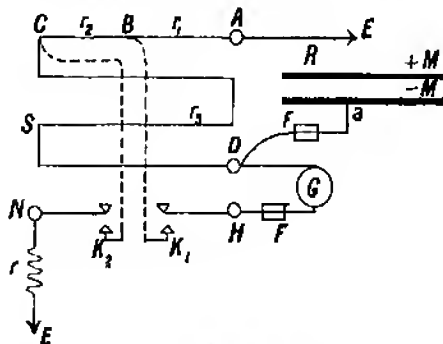


FIG. 48.

tested;  $r$  may be a few ohms or that offered by half-a-dozen or more glow lumps in parallel.

(2) With the proportional arms  $r_1$  and  $r_2$  arranged so that  $r_1 : r_2$  is as small as possible in order to obtain the adjustable arm  $r_3$  large, close  $K_1$  and then bring back the galvanometer deflection, thus produced, to zero by means of the controlling magnet.

(3) Then with  $K_1$  closed alter  $r_3$  so that on opening and closing  $K_2$  no motion of the galvanometer is observed. Then the insulation resistance of the system as a whole is  $R = \frac{r_1}{r_2} r_3$  ohms.

**Note.**—This method can be employed in the case of alternating current systems at work by placing a few cells of a battery in place of ( $r$ ) and using a galvanometer that will not indicate alternating currents. The mode of procedure is then the same as before.

### (47) Measurement of Insulation Resistance and detection of faulty Telegraph Insulators.

**Introduction.**—It is of paramount importance that all insulators intended for use on telegraph or telephone lines should be tested prior to their erection in the circuits. This will at once be evident when it is remembered that the insulators, supporting a line having an "earth return," form so many parallel circuits between the line and earth, and though the resistance to leakage of current of each insulator may be very great, yet their parallel resistance to the same may be very considerably less, allowing a very appreciable current leakage to go on to earth continuously. This, especially in telephone circuits, is very troublesome, causing the lines to interfere with one another, and besides this, speaking generally now, it gradually wastes away the batteries of cells used in working the lines. Again, the insulation resistance of a "line," composed of all very good insulators except one, will be lowered by the one single faulty cup to a value less than that of the faulty insulator.

Hence the importance of preventing, by a suitable and timely test, the installation of a bad insulator, which is generally found to deteriorate rapidly with time. Insulators should be tested, preferably before the bolts are inserted in them, and with an E.M.F. of from 160 to 300 volts after from 24 to 48 hours' immersion in a suitable manner in water. The value of the results of such a test will depend, however, very greatly upon the exact method of preparing the insulators and of applying the test, and some precautions have to be attended to in order to obtain a result which is trustworthy and *fair to the insulator itself*. The minimum insulation resistance which each insulator ought to possess depends on the length of the line on which it is to be used. In this country, during the worst wet weather conditions, it has been found possible to maintain a minimum insulation resistance of  $\frac{1}{2}$  megohm per mile on air lines, which is therefore taken as the minimum maintenance standard. Now the number of poles, and therefore insulators per mile of line, varies from 20 to 30 according to whether it is a branch or trunk



line. Hence, allowing the latter number, each insulator should have a resistance of at least 6 megohms if the line were only one mile long, 60 if 10 miles long, and 600 if 100 miles long, and so on, in the worst wet weather. As a matter of fact the resistance of a double shed or cup porcelain insulator, if a good one, may vary under testing conditions from 500,000 megohms to something like 4,000,000 megohms.

**Apparatus.**—Shallow trough *T* lead-lined inside, to which is attached the terminal *N* making contact with the lead; insulators to be tested  $I_1$ ,  $I_2$ , etc., only these two being shown; battery *B* capable of giving 100 to 300 volts E.M.F. and consisting of either Daniells, secondary or other convenient cells; very sensitive high resistance reflecting galvanometer *G* with its shunts (*S*); high insulation two-way key *K* (p. 586); high insulation test rod *t* connected to *K* by a well-insulated length of gutta-percha covered wire; standard megohm *r*.

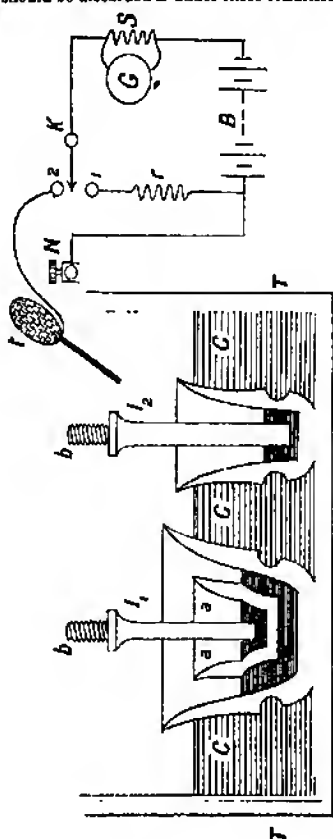
**N.B.**—In this and all other similar high resistance tests, the connections should be in mid air as much as possible, and all insulating material quite clean and free from dust and finger-marks.

Assuming all the insulators to be perfectly clean on the inside and outside of their sheds, there are two modes of procedure, in each of which they are immersed in the trough *T* with the water up to within half-an-inch of the lips of their outside walls. Thus—

(a) The whole of the inside of each insulator kept clean and dry, the resistance then from bolt (*b*) to water being very approximately their *insulation resistance* under working line conditions. This is usually so high that the galvanometer is not sensitive enough to indicate the extremely small current passing unless the insulator is actually defective. If it is all right the only way usually to obtain a deflection is to test from 100 to 200 in parallel at one time.

(b) The inside of the shed or sheds carefully filled with water by means of a pipette to within half-inch of the lips, the resistance now from bolt (*b*) to outside water showing whether the insulator is faulty through the leakage current passing through its substance, assuming the unimmersed lips to be *clean and dry*. The

insulator should be discarded if under these conditions it does not



**Fig. 48.**

show 600 magohms at least, preferably 2000, which is the minimum in some telegraph services.

In the following test we shall adopt the latter mode of testing, since the former is in most cases impracticable.

**Observations.**—(1) Carefully clean the porcelain or earthenware portion of each insulator, especially the lips, with clean cold water. Then dry the lips merely in a place free from dust, and place them with their bolts pointing upwards (Fig. 49) in the tank *T*, packing up the smaller ones so that all the lips are at about the same level, but not touching one another.

(2) Now pour water into *T* to within half-inch of the lips and into the cups, by means of a pipette, to the same level. Then allow the insulators to soak for about forty-eight hours (in a place free from dust), so that the water will percolate or soak into any cracks or flaws in the mass of the earthenware.

(3) Before testing, hold a hot iron close over the rims of each insulator for a short time to dry off any moisture, as it is necessary that **THESE PARTS SHOULD BE QUITE DRY**. For this reason avoid testing on a damp day, unless the air of the room is dry.

(4) Connect up as shown in Fig. 49. Test the insulation of the connections between *t* and *k* before each set of observations. This will be satisfactory if *G* does not deflect when the connecting wire is supported in mid-air when *t* is held in the hand.

(5) With the galvanometer at zero and the  $\frac{1}{1000}$ th shunt in, close *K* 1, so as to bring  $r$  into circuit, and note the steady deflection (*d*), then close *K* 2 (opening *K* 1) and touch the bolt of each insulator successively with *t*, noting the deflections *D* in each case if any.

(6) Repeat 4 and 5 for the  $\frac{1}{10}$ ,  $\frac{1}{100}$  and no shunt if possible.

(7) In the case of the double-shed insulators, such as *I*<sub>1</sub> (Fig. 49), touch the water between the sheds with *t*, thus obtaining the resistance of the outer shed. Next connect metallically the water between the sheds, and also that outside, and touch the bolt with *t*, thus getting the resistance of the inner shed.

(8) The approximate resistance of all those insulators which show an extremely high insulation can be obtained by paralleling them or joining their bolts together metallically, and then

taking a reading (as in 6), first with the  $+$  of the battery to  $T_1$  and second with the  $-$  to  $T_1$ , the insulators being discharged in between the two reversals. Calculate the average of each insulator from the combined or parallel resistance so obtained.

(9) Employ the formula given below, or its modification, and tabulate your results as follows—

NAME . . .					DATE . . .			
Galvanometer Resist. $G = \dots$ Ohms at $\dots^\circ \text{C.}$					Internal Battery Resist. $\omega = \dots$ Ohms.			
Insulator tested.	After how many hours of immersion.	Distance of Water from top.	Temp. of Room.	E M F used.	Shunt S.	Deflection.		Known Insulation $R_1$ .
						known $d_1$ .	unknown $d_2$ .	

$$d \left\{ r \left( 1 + \frac{G}{S} \right) + G \right\} = D \left\{ R \left( 1 + \frac{G}{S} \right) + G \right\}.$$

$$\text{If } S = \frac{1}{2} \text{ (say), then } \frac{S}{S+G} = \frac{1}{10} \text{ or } \left( 1 + \frac{G}{S} \right) = 10.$$

$$\text{If no shunt is used } S = \infty \text{ and } \therefore \frac{G}{S} = 0.$$

#### (48) Measurement of the Insulation Resistance of Storage Batteries.

**Introduction.**—In the erection of a storage battery, provision is made for the efficient insulation of every cell composing the battery, from earth, by supporting each on suitable insulators, and keeping the cells from touching one another. Notwithstanding these precautions, leakage of current, from various causes, may go on in a greater or less degree. It may occur in different parts of the battery, or in the leads running from the battery, and the resistance opposing the leak may, and usually does, have different values at different parts of the battery; in other words, the partial "earths" at the various points are of unequal resistance, which prevents the insulation resistance being obtained by an ohmmeter or other portable testing set.

The difficulties thus met with are got over by employing the present method due to Mr. E. S. Jacob, and which at once gives the joint resistance of all the earths at whatever points of the battery they may be located.

**Apparatus.**—Sensitive high resistance galvanometer  $G$ ; adjustable known resistance box ( $r$ ); battery  $B_1 \dots B_2$  to be tested, there being any number of cells between the two  $B_1$  and  $B_2$  shown. Key  $K$  of very good insulation (p. 586), battery stands, or equivalent earth  $E$ .

N.B.—Earths or partial ones, i. e. leaks, may be assumed to

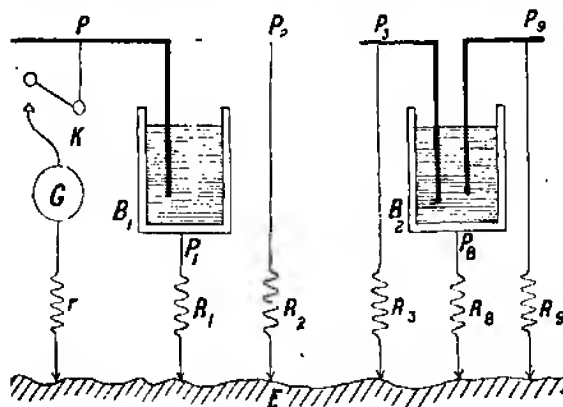


FIG. 50.

occur at points  $P, P_1 \dots P_n$ , etc., and  $r, R_1 \dots R_n$  to be the respective resistance of such earths.

**Observations.**—(1) Connect the key  $K$ , galvanometer  $G$ , and resistance box ( $r$ ) to the battery system at any point  $P$ , as shown in Fig. 50,  $E$  being earth, i. e. the nearest gas- or water-pipe, and adjust the galvanometer needle to zero.

**Note.**—Choose the point  $P$ , so that a conveniently large deflection is obtained on  $G$ , for it will be found that there is a certain point of minimum potential from which it increases on either side as the contact is moved one way or the other.

(2) With  $r = 0$ , press  $K$  and note the current  $C_0$  and, for reference only, the relative position of the point of contact  $P$  on the system.

(3) With everything the same as in 2, adjust ( $r$ ) so that on pressing  $K$  the new current  $C_r$  on  $G$  is about  $\frac{1}{2} C_G$ . Note the resistance  $r$  and this deflection or current  $C_r$ .

(4) Repeat 1-3 for two or three different values of  $r$ .

(5) Repeat 1-4 for two or three different points of contact  $P$ .

(6) Calculate the insulation resistance of the whole battery from this relation—

$$R = \frac{C_r (g + r) - C_G g}{C_G - C_r} \text{ ohms,}$$

and tabulate as follows—

Name . . . . . Date . . . . .  
 Battery: Type . . . . . Containing boxes of . . . . . No. of cells . . . . .  
 Galvanometer Resistance  $g = \dots$  Ohms @  $\dots^\circ \text{C}.$

Relative position of $P$ .	Value of $r$ Ohms.	Current $C_r$	Current $C_G$	Insulation Resistance $R$ Ohms

**Inference.**—Prove the relation given in 6, and state any assumptions made in obtaining it. On what does the accuracy of the test depend?

#### (49) Insulation Resistance of Dynamos and Motors.

**Introduction.**—Since the total amount of leakage from a system of electrical distribution depends on the number of appliances connected to the system, which represent so many parallel paths for leakage currents to take, it is of great importance to increase the resistance in these paths, and so diminish, as much as possible, such currents. This, in other words, means that the insulation resistance of all appliances on the system should be as high as possible. Hence it becomes of importance to carefully measure the insulation resistance of motors and dynamos, both in course of manufacture and when installed before running is commenced.

The Institution of Electrical Engineers recommends that the leakage current should not be allowed to exceed  $\frac{1}{1000}$ th part of the maximum current in the system at full load. As a general rule the total insulation resistance of all the insulated parts of a dynamo or motor, joined together, from the frame of the machine,

i. e. earth, should be at least equal to that of the rest of the circuit which it has to run on, but preferably much greater. The present test is a simple and convenient one for obtaining the insulation resistance of, say, a dynamo, and is as follows—

**Observations.**—By means of a high resistance voltmeter of resistance  $R_v$  ohms measure the P.D.  $V$  at the terminals of the machine when running at normal voltage not connected to any circuit. Also measure the P.D.s  $V_1$  and  $V_2$  between the + and - brushes and the frame of the dynamo. Then we shall have—

Total insulation resistance of the machine

$$R = \frac{V - (V_1 + V_2)}{V_1 + V_2} R_v \text{ ohms.}$$

### (50) Localization of Faults in Electric Mains. (Murray's Loop Method.)

**Introduction.**—In the preceding pages, some of the best and most important methods of measuring the insulation resistance of electric mains have been dealt with, but the localization of the position of any prominent and serious fault in such is a matter of equal, if not greater, importance. The insulation of the cable may or may not have broken down at the fault, but obviously in either case, since the opening up of the duct in which the cables are laid is often a serious matter in a busy thoroughfare, it is important to be able to localize the position of the fault to within a very few feet.

There are two important methods or systems of localizing faults, each comprising modifications of the principles employed, viz.—

(A) "Loop" methods. (B) "Fall of Potential" methods.

The latter, though extremely simple, are less easy of application than the former, and must be applied so as to suit the conditions of the particular fault. *Loop methods* are much more generally applicable, and are preferable for the following reasons—

- (1) They are "null" or "zero" methods.
- (2) They are easier to work.
- (3) The accuracy is not affected by variations of the fault resistance.

(4) The test is performed in the same way for mains of any section and whatever the fault resistance.

We shall therefore restrict ourselves to one of the best of these loop methods, but before taking it in detail there are a few remarks which must be made.

Loop methods require a continuous circuit of main or cable from the place where the testing instruments are, through the faulty portion and back again, which is termed the *loop*. The two portions of cable between fault and instruments should have good insulation resistance, but need not have the same sectional area throughout. Referring to Fig. 51, let  $MSN$  be a cable, the two ends of which cannot be brought closer to the terminals  $A$  and  $C$  of a Wheatstone Bridge than the points  $M$  and  $N$  respectively.

• Let there be a fault at some point  $P$  between the core of the cable at  $P$  and the earth  $E$ , the resistance to earth being much less than that at any other point. This is called the fault resistance, and may be represented by  $r$ .

The fault might be on the "outer" of a concentric main, in which case the "inner" and "outer" conductors would be carefully joined at the further end  $S$ , so as to form a complete circuit or loop.

In fact, in practice we should either be dealing with this case of a concentric main or with a fault on one of a pair of separate mains.

In either case the loop would be formed by making the *best possible joint* between the two ends furthest from the testing point, by disconnecting them from any terminals to which they might be clamped. Now it is obvious that the cable ends  $M$  and  $N$  cannot be clamped under the terminals of the bridge, owing to their size and to them terminating in a position in which it would be impossible to have the testing apparatus. Smaller connections  $AM$  and  $CN$  must therefore be used and also allowed for in working out the results of observations, and this is done as follows—

Let  $D_1$ ,  $D_2$  = distances from  $M$  and  $N$  respectively to the looping point,

and  $d_1$ ,  $d_2$  = distances from  $A$  to  $M$  and from  $C$  to  $N$  respectively,

$s$  = sectional area of either conductor of the main  $MSN$ ,

$s_1$  and  $s_2$  = sectional area of the connections  $AM$  and  $CN$  respectively.



Then, since resistance is directly  $\propto \frac{\text{length}}{\text{section}}$ , we see that  $AM$  has the same resistance as, or is equivalent to a length of the main  $MSN = \frac{s}{s_1} d_1$  and  $CN$  to a length  $= \frac{s}{s_2} d_2$ .

Hence the bridge will behave as if the resistance between  $C$  and  $P$  (which = resistance of  $CN$  + resistance of  $NP$ ) was that = to a length of the main cable  $= D_2 + \frac{s}{s_2} d_2$ .

The whole length of circuit  $L$  between  $A$  and  $C$  is—

$$\therefore L = D_1 + \frac{s}{s_1} d_1 + \frac{s}{s_2} d_2 + D_2.$$

The expression or value for  $L$  may very greatly be simplified by making  $D_1 = D_2$  and also  $d_1 = d_2$ , which latter can easily be done, and by choosing single wires for the connections  $AM$  and  $CN$  of the same gauges as each wire of the strand forming the main  $MSN$ . Thus if the main was  $\frac{1}{16}$  in size, use  $\frac{1}{16}$  for the connections.

If this is done and  $n = N^\circ$  of wires in the strand of either conductor of the main,

$$\text{then } L = 2D + 2 \cdot n \cdot d = 2(D + n \cdot d).$$

The lengths of  $AM$  and  $CN$ , though =, should be as short as possible, so that their resistance is not large compared with that of the main cable.

**Apparatus.**—Post-office or other pattern Wheatstone Bridge; sensitive galvanometer  $G$  (p. 569); battery  $B$  of Leclanché cells; fuse  $F$ ; resistance  $R$ ; suitable connections  $AM$  and  $CN$  and main to be tested.

**Note.**—A few secondary or primary cells may form the battery  $B$ , and if the fault resistance  $r$  is anything like 1000 ohms, a battery giving 100 volts might be used. The fuse  $F$  is to prevent the bridge coils being fused up should  $r$  break down unexpectedly, and it can be dispensed with if a primary battery is used. It is as well to earth the battery, if not a primary one, through a resistance  $R$  of a few ohms.

The more sensitive  $G$  is, the greater the accuracy of the test, and quite small wires may be used to connect  $G$  and  $B$  up, as their resistances do not affect the accuracy of the test.

**Observations.**—(1) Connect up as shown in Fig. 51, and adjust the galvanometer  $G$  nearly to zero. See that a very fine fuse is inserted in  $F$ , if necessary at all, and make fairly good earths at  $EE$ . Good soldered joints at  $M$ ,  $N$  and the looping point are practically indispensable, as well as good tight clean contacts at  $A$  and  $C$ . Inattention to these points will vitiate the results.

(2) Plug up  $r_1 = 0$  and unplug  $r_2 = 1000$ , with, say, the *Infinity* plug out in  $r_3$ .

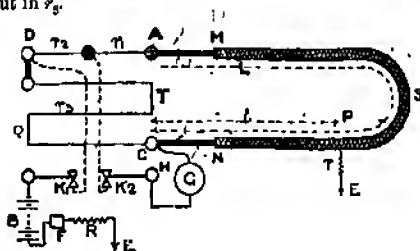


FIG. 51.

(3) Press  $K_1$  first and then tap  $K_2$  for an instant, observing which way  $G$  deflects for  $r_3$  so great.

If on inserting "*Inf.*"  $G$  deflects the other way on manipulating  $K_1$  and  $K_2$  as before, then a balance can be obtained by adjusting  $r_3$  so that  $G$  does not deflect on pressing  $K_1$  and then  $K_2$ . Note the value of  $r_2$ ,  $r_3$ . If no balance can be found, the fault  $P$  is very close to  $M$  or  $N$  when the connections to  $A$  and  $C$  should be interchanged.

(4) If the balance appears to be insensitive  $r_2 = 100$  or 10 may be tried and (obs. 3) above repeated.

(5) Calculate the equivalent distance of the fault  $P$  from the terminal  $C$  by means of the relation

$$l = \frac{r_2}{r_2 + r_3} \cdot l_1,$$

and tabulate your results in a convenient way.

N.B.—The distance of  $P$  from  $N$  therefore  $= l - \frac{x}{x_1} \cdot d_1$ .

(6) Interchange the connections to  $A$  and  $C$  and repeat obs. 2-5, and if the result now given is close to the previous one, take

the mean of the two as the correct one. If they differ considerably, the contacts are bad and must be improved.

In this latter test the distance of  $P$  from  $A$  is given by

$$l = \frac{r_2}{r_2 + r_3} L,$$

### (51) Calibration of Speed Indicators.

**Introduction.**—There are many different forms of speed indicators or tachometers, as they are frequently termed, some of which vary in accuracy with the time for which they are in use. It thus becomes of importance to standardize such instruments at frequent intervals when accuracy is required. This can be done either by comparison with an accurately calibrated tachometer specially reserved for this purpose only, or by taking simultaneous readings on the instrument to be checked and time readings on a speed counter. This latter method, being the more generally applicable of the two, will be the one here considered.

**Apparatus.**—Tachometer to be tested; speed- or revolution-counter; stop-watch if available, or in lieu of this an ordinary watch with a "seconds-hand."

**Observations.**—(1) Arrange the tachometer so that it can be driven by some machine at a variety of speeds, each of which may be maintained constant for at least one minute. This driving machine must have a turned centre in one end of its shaft into which can be pressed the centre of the spindle of the revolution-counter.

(2) Drive the tachometer at the lowest convenient speed readable on its scale, and take the dial readings ( $D_1$ ) of the revolution-counter. When this speed is constant (as will be observable by the instrument itself) insert the counter in the end of the driving-shaft at a noted instant of time, using a light pressure. Quickly take the counter away, the instant one minute has elapsed, and note the readings ( $D_2$ ) of its dials. Then  $(D_2 - D_1) =$  speed in revolutions per minute.

(3) Repeat 2 twice or three times at the same speed, and record the mean.

(4) Repeat 2 and 3 for some eight or ten readings on the tachometer, rising by about equal increments to the maximum.

(5) Check some of the readings obtained in 2-4 by taking observations over two minutes.

(6) If the tachometer is adjustable, alter it so that its indications give the correct speed in revolutions per minute. If unadjustable, plot a calibration curve having values of true speed as abscissae and tachometer readings as ordinates.

## (52) Measurement of Rotational Speed by the Stroboscopic Fork.

This method has been in use for measuring the speed of generators and motors for many years. See papers by Dr. C. V. Drysdale—(1) on "Stroboscopy"; read at the Optical Society, London, in 1905, and reprinted in *The Optician and Photographic Trades Review*, Dec. 8 and 15, 1905. (2) "Accurate Speed, Frequency, and Acceleration Measurements," *Electrical Review*, London, Sept. 7 and 14, 1905. Previous to that it had been used by scientists, e.g. to measure the speed of a small driving motor to within  $\frac{1}{60}$  of 1% in the Lorenz apparatus for determining the absolute value of the ohm.

The stroboscope used comprises essentially—(1) either a hand vibrated, or (preferably) an electro-magnetically vibrated tuning fork

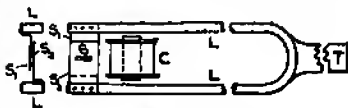


FIG. 52.

fitted with two shutters, each containing a narrow slit, and (2) a discoidal target of observation.

The stroboscopic fork unmounted is indicated diagrammatically in Fig. 52, and that used by Dr. Drysdale consists of a steel tuning fork, the limbs *LL* of which are approximately 12" long  $\times \frac{1}{32}$ " wide  $\times \frac{1}{8}$ " thick, and are supported by a tail-rod *T*

clamped in a suitable frame or stand (not shown). To the extremities of  $LL$  are screwed two light and thin metal strips or flat shutters  $S_1, S_2$  ( $1\frac{1}{2}'' \times 1\frac{1}{8}''$ ) in the plane of vibration, each containing a narrow slit  $S$  ( $\frac{3}{8}''$  long) parallel to the length of  $LL$ . These slits are exactly opposite to one another when the fork is at rest, so that in this condition the eye can see through both slits. When hand vibrated the fork, while being held in the observer's hand, is excited into vibration at intervals by mechanical impulses derived from a light blow on the knee.

When electro-magnetically operated, the "make and break" principle used in the electric trembling bell is adopted—an iron-cored coil  $C$  being mounted between  $LL$  on a support (not shown) adjustable, for convenience, in a direction parallel to  $LL$ .

This actuating coil  $C$  is energized from one or two dry cells through a "contact breaker," formed by two platinum-tipped contacts—one on a fixed support, the other on a very light flat spring fixed to one of the limbs  $L$ . Now when the fork is excited into free vibration, the line of vision through the slits  $S$  is interrupted by the vibrating shutters  $S_1, S_2$  except during a very brief interval, once in each half cycle, or twice in each complete cycle of the vibration, at the moment when the slits  $S$  pass each other, moving rapidly in opposite directions. If, then, an object viewed through the slits  $S$  is rotating so that consecutive images conveyed to the eye are similar and symmetrical, that object will appear to the eye to be continuous and stationary, although actually rotating at a high speed.

Further, a certain cyclic departure from absolute similarity and symmetry in the successive images seen by the eye will make the object appear as if it was rotating. If the object appears at a standstill when seen through  $S$ , its speed must be constant, and must bear a simple proportion to that of the vibration of the fork. Therefore, since the rate of vibration of a tuning fork is always very constant at all times, and almost independent of change of temperature (varying only about 0.01% per deg. cent.), it can be determined once for all with great accuracy, and hence also any speed by comparison can be measured with like accuracy.

If a fork vibrates with a frequency of 50 cycles per sec., the eye will receive 100 impressions of the object through the slit *S* per second, and will have 6000 peeps per minute. The geometrical form of the rotating object viewed through the slit will, in conjunction with the rate of vibration of the fork, decide the speeds at which the object will appear at a standstill. These speeds might, for example, be 100, 200, 300, etc., revs. per min., and the simple fork shown in Fig. 52 can only serve to measure speeds intermediate between these by enabling the eye to count the apparent revs. made by the object in one minute by a watch. For example, if the speed at which the object—viewed through the slit appeared stationary—was 1500 revs. per min., and afterwards the object appeared to be rotating in the direction of motion at 50 revs. per min., then the actual speed of the object would be 1550 revs. per min. If this apparent rotation of the object was in the opposite direction, the actual speed would be 1450 revs. per min.

The determination in this manner of speeds intermediate between the two nearest standstill values, coupled with the necessity for such being constant, is a disadvantage in the stroboscopic method, for it is obviously preferable to be able to bring the object to an apparent standstill at any speed. At least two methods of doing this have been devised: one due to Dr. Drysdale employs a special arrangement of a conical roller with stroboscopic disc, as described in his paper, but which lacks portability. In another method, designed for portability by Messrs. A. R. Kennelly and S. E. Whiting, and described by them in a paper read at the Twenty-fifth Annual Convention of the Amer. Inst. E.E., Atlantic City, N.J., June 29—July 2, 1908, the stroboscopic fork is adjustable continuously in its rate of vibration through a range of about 5% above and below its mean value without sensibly disturbing its motion. This is done by a pair of sliding weights, which are moved friction tight along about  $7\frac{1}{2}$ " of the limbs of the fork, gradually from one position to another, by a pair of strings, normally slack, passing over guide-pulleys, and vibrating with the fork. The form used in this design has limbs 18" long  $\times$  1" wide  $\times$   $\frac{1}{8}$ " thick, and weighs by itself almost 2 lbs. The object in using so long a fork was to obtain a low frequency vibration or fork-

speed comparable with the speeds ordinarily met with in rotating machinery. The fork has a mean speed giving 1900 peeps per min., and carried on its extremities a pair of thin sheet steel shutters with slits  $0.59''$  long  $\times$   $0.008''$  wide. Adjustments are provided for aligning these slits, and for tuning the fork to the required normal frequency. It is operated by an electro-magnet, the coil of which is wound with 525 turns of No. 27 S.W.G. enamel insulated copper wire (enamelled to No. 20 S.W.G.), having a resistance of about  $3\frac{1}{2}$  ohms, and requiring an average current of about 0.15 amp. to operate the fork through a form of contact breaker already referred to.

The amplitude of the vibration of the fork limbs is about  $\frac{1}{8}''$  at the slits, each side of their position of rest, giving a maximum cyclic velocity of about 1 foot per sec. at normal fork speed. The relative velocity of the slits is thus about 2 feet per sec., and the duration of each peep through the slits will be  $\frac{1}{3000}$  of a sec.  $= \frac{1}{180000}$  of a min. Hence an object rotating at 1800 revs. per min. will only move through  $\frac{1800}{180000} = \frac{1}{100}$  of a revolution during each peep, and if it appears at a standstill through the slits, 1 rev. per min. more or less, i.e. a variation of  $\frac{1}{18}$  of 1% in the speed will cause the object to make 1 rev. per min. either way.

**The Target**—hitherto called the rotating object, may most conveniently consist of a thin disc (between 9'' and 10'' in diam.) of sheet metal or thick cardboard fixed concentrically—in any convenient and satisfactory way—to the end of the shaft whose speed is to be measured. If neither end of the shaft system is available, nor any portion of the end of the machine suitable for use as a target, it may be possible to mount the special artificial target on a subsidiary spindle with pulley, and



FIG. 53.

drive this by a light supply tape belt at a definite speed ratio from some part of the machine under test.

From many trials with different kinds of targets, it has been

found that a pure white pattern on a deep black grounding, and of about the size above-mentioned, is quite satisfactory. The pattern (Fig. 53) comprises: a square, a pentagon, a hexagon, a 14-point star, and an 18-point star, all concentric with one another, and with the disc and shaft, with a radial bar inside the square for enabling the apparent revolutions between intermediate standstill speeds to be counted easily.

If  $P$  = number of positions of symmetry per revolution of any individual pattern on the target,

$n$  = revs. per min. of the target.

$N$  = any whole number or reciprocal of a whole number,

and  $p$  = number of peeps per min. given by the fork's rate of vibration.

Then the particular pattern will stand still when viewed through the slits if

$$N = \frac{Pn}{p}$$

For example, the square or 4-pointed star has  $P = 4$  positions of symmetry per revolution.

If a given fork provides  $p = 3600$  peeps per min.,

Then the square will appear to stand still for actual speeds of—

$$n = 450 \text{ revs. per min. at which } N = \frac{Pn}{p} = \frac{4 \times 450}{3600} = \frac{1}{2}$$

the reciprocal of a whole number,

$$\text{and } n = 1800 \text{ revs. per min. at which } N = \frac{Pn}{p} = \frac{4 \times 1800}{3600} = 2$$

a whole number.

In the first case the square will move through half of a position of symmetry, and in the second case through two positions of symmetry between successive peeps.

The useful possibilities obtainable with the above target may be conveniently seen in Table VI.

The higher the actual speed of rotation, the greater must be the rate of vibration or frequency of the slits and number of peeps per min., and the narrower must the slits be, otherwise the number of positions of symmetry  $P$  must be smaller to give an increase of pitch.

The accuracy of this method of measuring speed is very high, and of the order of about 1 part in 10,000.



TABLE VI.—Actual speeds in r.p.m. at which each pattern of the Target (Fig. 53) will appear to stand still when viewed through the slit of a Fork giving 1000 peeps per minute.

Square.		Pentagon.		Hexagon.		14-Pointed Star, P = 14.	17-Pointed Star, P = 17.
P = 4 or 1.	P = 8 or 1.	P = 5 or 1.	P = 10 or 1.	P = 6 or 1.	P = 12 or 1.		
Image stationary at every 450 r.p.m. = $\frac{1}{2}$ Synchr. Speed.	Image appearing doubled, but less clear at intermediate speeds or every 225 r.p.m. = $\frac{1}{4}$ Synchr. Speed.	Image stationary at every 800 r.p.m. = $\frac{2}{3}$ Synchr. Speed.	Image appearing doubled, but less clear at intermediate speeds or every 160 r.p.m. = $\frac{1}{3}$ Synchr. Speed.	Image stationary at every 900 r.p.m. = $\frac{3}{4}$ Synchr. Speed.	Image appearing doubled, but less clear at intermediate speeds or every 150 r.p.m. = $\frac{1}{4}$ Synchr. Speed.	Image stationary at every 128 6 r.p.m. = $\frac{1}{14}$ Synchr. Speed.	Image stationary at every 100 r.p.m. = $\frac{1}{17}$ Synchr. Speed.
—	225	—	160	—	150	128 6	100
450	450	800	320	900	300	514 2	200
—	675	—	480	—	450	385 8	300
900	900	1200	720	600	600	514 4	400
—	1125	—	960	—	—	614 0	500
1350	1350	1600	—	750	750	771 6	600
—	1575	—	1280	900	900	949 2	700
1800	1800	2400	1920	—	1050	1678 8	800
—	2025	—	1600	1200	1200	1577 1	900
2250	2250	1800	1800	—	1350	1280 0	1000
—	2475	—	1440	1500	1500	1411 6	1100
2700	2700	2160	2160	—	1650	1648 2	1200
—	2925	—	2400	1800	1800	1671 0	1300
3150	3150	2520	2520	—	1950	1800 4	1400
—	3375	—	2700	2100	2100	1922 0	1500
3600	3600	2880	2880	—	2250	2047 8	1600
—	3825	3060	3060	2400	2400	2146 2	1700
4050	4050	3240	3240	—	2550	2214 0	1800
—	4275	—	3420	2700	2700	2313 4	1900
4500	4500	3600	3600	—	2850	2372	2000
—	—	—	—	3000	3000	—	—

### (53) Relation between Speed and E.M.F. in "Separately Excited," "Shunt," and "Compound Wound" Direct Current Dynamos.

**Introduction.**—The following tests are arranged with the object of investigating the way in which the terminal E.M.F. of the various types of dynamos varies with the speed when the machine is delivering no external current. The mode of procedure is exactly the same for each type of machine, and consequently this will be given in one concrete instance only, and merely referred to afterwards for the others. In all cases the terminals  $T_1$ ,  $T_2$  of the machine are the ones to which the external circuit would be directly connected. Prior to starting see that all lubricating cups in use contain oil, and feed properly

but very slowly; also that the commutators are smooth and clean, and the brushes properly trimmed.

**N.B.**—The performance of a "magneto" machine would be exactly similar to that of (A) below, and the "series" machine approximately the same also, providing the current through the series machine be kept constant by varying the circuit resistance as the speed varies.

**Apparatus.**—Dynamo *D* to be tested; tachometer; voltmeter (*V*) capable of reading sufficiently high.

(A) SEPARATELY EXCITED DYNAMO.

**Observations.**—(1) Connect up *V* to  $T_1 T_2$ , and the exciting coils to some outside source of E.M.F. through an ammeter (*a*), and rheostat (*R*), then start *D*. Adjust (*R*) so as to obtain a current which will give  $\frac{1}{2}$  max. excitation (to be kept constant).

(2) Adjust the speed so as to obtain the lowest readable scale reading of *V*. Note this and the speed.

(3) Raise the speed so as to get about ten different values of *V*, rising by about = increments to the max., and note the speed at each.

(4) Repeat 3 for a similar descending set of readings.

(5) Repeat 3 and 4 for such a current through the field coils as will give max. excitation, and tabulate your results in the following general form.

Type of Dynamo tested.	Speed in Revs. per min.	Exciting Current in (a) amperes.	Terminal E.M.F.	
			Ascending <i>V</i> .	Descending <i>V</i> .

(B) SHUNT DYNAMO.

**Observations.**—(1) Connect up *V* to  $T_1 T_2$ , and start the dynamo.

(2) Repeat observation (2—4 A), and tabulate in the form shown above.

(C) COMPOUND WOUND DYNAMO (LONG SHUNT).

**Observations.**—Repeat those for *B* above.

Plot curves for the tests on each type of machine in *A*, *B* and *C* above, having E.M.F. as ordinates and speed as abscissæ.

**Inferences.**—Compare the above curves and results, and state clearly all that you can infer from them.

### Characteristics of Dynamo Machines.

**Introductory Remarks.**—There are two great classes of electrical generators for converting mechanical into electrical energy—namely, (1) those which supply *continuous* current, i.e. current which flows in one direction only round the circuit, and which are otherwise styled *direct current dynamos*; (2) those which supply *alternating* current, i.e. current that reverses its direction throughout the whole circuit many times a second, and which are usually styled *alternators*. As therefore the supply of electrical energy to any appreciable extent invariably assumes one or other of the above forms of current, a study of the behaviour of the machines that supply it becomes of paramount necessity. Restricting our considerations first of all to the former of the above-mentioned classes, it may be remarked that it is composed of a great variety of forms, the performance of which depending practically entirely on the method employed in winding their field magnets, in other words, as to whether the whole, a fraction, or a combination of this whole and the fraction of the whole current generated by the machine is utilized in magnetizing their field magnets. Direct current dynamos in general may consequently be subdivided into the following five distinctive types according to the winding of their field magnet coils—

- (a) Magneto machine.
- (b) Separately excited machine.
- (c) Series machine.
- (d) Shunt machine.
- (e) Compound machine.

All these types are used in practice, especially the last three, which form by far the greater proportion of direct current machines in use throughout the world. Only by a minute study of the performance and action of each type can it be seen which of them is the best suited for any particular purpose.

The current that any particular dynamo will send through a given external circuit connected to its terminals will obey Ohm's Law, and will depend on the E.M.F. of the machine, as well as on this external resistance.

If therefore the machine be run at a constant speed, and the

circuit resistance  $R$  varied by suitable steps (say), both the terminal P.D. of the machine ( $V$ ) and the current  $A$  will vary. Assuming that  $V$  and  $A$  are noted simultaneously for each alteration of  $R$  we can plot a curve having values of  $V$ , measured along the ordinates, and  $A$  along the abscissae, these axes being rectangular. Such a curve is commonly called the "*external Characteristic*" of the dynamo, and by means of it many valuable and practical details can at once be deduced.

In fact, the function of a Characteristic in relation to a dynamo is extremely analogous to that of an "Indicator diagram" with an engine. In the former, not merely can the qualities and performance when working be seen, but also the H.P. at which it works or could most economically work at, and many defects in the design—such as the sufficiency of the field magnet field, the degree of saturation of the magnets, the demagnetizing action of the armature on the field, etc., etc. The Characteristic of a dynamo is therefore much more important to the electrical engineer than the author ventures to think is generally supposed.

#### (54) Determination of the "External Characteristic" of a Magneto Dynamo.

**Introduction.**—The present type of machine under consideration has a somewhat extensive field of use, two very important applications being for blasting purposes and use with the ohmmeter, and indeed in all kinds of work in which a portable E.M.F. and small current is desired.

Another application in the past on a heavier scale was in the production of lighthouse search-lights, in which kind of work heavy currents are required at a comparatively low E.M.F. Considering the machine more in detail, when the armature is delivering no current to the external circuit, the terminal P.D. ( $V$ ) = the total E.M.F. ( $E$ ) of the dynamo. When, however, a current  $A$  flows, then  $V$  is less than  $E$  by an amount depending on the armature resistance  $r_a$ ; for, by Ohm's Law,

$$\text{we have } E = A(R + r_a)$$

where  $R$  = the resistance of the external circuit; but since it is solely the P.D. ( $V$ ) which drives the current through the external resistance,

$$\therefore V = AR,$$

$$\text{and consequently } E = V + Ar_a.$$

Thus we see that the total E.M.F. of the dynamo is = the P.D. at

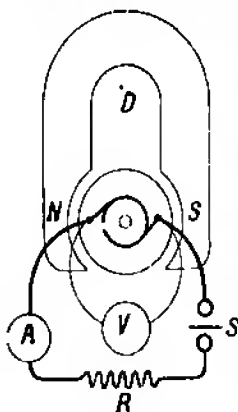


FIG. 54.

the terminals + that required to send the current  $A$  through the internal resistance  $r$  of the armature. The permanent magnetism of the steel magnets is approximately constant.

**Apparatus.**—Magneto dynamo  $D$  to be tested; voltmeter  $V$ ; ammeter  $A$ ; switch  $S$ ; rheostat  $R$  (p. 606); tachometer.

**Observations.**—(1) Connect up as in Fig. 54, and adjust the pointers of  $A$  and  $V$  to zero, if necessary. See that all lubricating cups in use feed slowly and properly, and that the commutator is smooth and clean, and the brushes properly trimmed.

(2) Start  $D$  up to its normal speed, and when this is constant, note the reading of  $V$ .

(3)  $R$  being as large as possible, close  $S$ , and take a series of about ten different values of current  $A$ , rising by about equal increments from the smallest to the maximum permissible. Note the voltage  $V$  and current  $A$  for each, the speed being constant at the above value.

(4) Repeat 2 and 3 for a similar descending set of readings of  $V$  and  $A$  at the same speed.

(5) Repeat 2-4 for speeds 20% above and 50% below normal respectively.

(6) Measure the armature resistance ( $r_a$ ) (while warm) by the Wheatstone Bridge, or if it is too low, by the "Potential Difference" method (p. 84), or by the ammeter and voltmeter method (p. 86), and tabulate your results as follows—

Name . . .

Date . . .

Magneto Dynamo tested: No. . . . Type . . . Maker . . .  
 Normal Voltage = . . . Amps. = . . . Speed = . . . Revs. = . . .

Speed Revs. per min.	Ascending.		Descending.	
	Terminal Volts ( $V$ )	Amps. ( $A$ )	Terminal Volts ( $V$ )	Amps. ( $A$ )

(7) Plot the *external Characteristic curves* of the machine for both the ascending and descending readings at each speed on the same curve sheet, having values of  $V$  as ordinates and  $A$  as abscissae.

(8) Deduce from these the *total Characteristics* of the machine by the graphical construction given below, drawing them on the same curve sheet (*vide* p. 3, obs. 8).

(9) Plot the horse-power curves (see below) to the same axes.

**Inferences.**—State clearly all that you can infer from your experimental results.

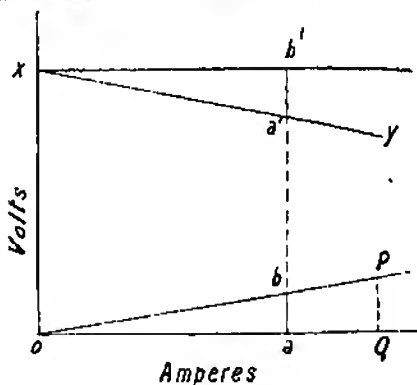


FIG. 55.

### Graphical Deduction of the Total Characteristic of a Magneto Dynamo from its External Characteristic.

Referring to Fig. 55: take two co-ordinate axes having their origin in the point  $O$ . Let  $zy$  be the *external Characteristic*. Take any point  $Q$  in the abscissae representing some definite current  $OQ$  to the scale chosen, and set off on the ordinates  $QP = OQ \times r$ , volts.

Join  $OP$ , which therefore represents the fall of Potential through the armature due to the currents flowing in it,

$$\text{or } \tan. POQ = r.$$



### Horse-Power Curves.

- \* Since the electrical power  $W$  in Watts developed by any dynamo giving a current  $A$  amps. at a P.D. of  $V$  volts is—

$$W = AV \text{ (Watts)}$$

and since 1 H.P. = 746 (Watts),

$$\therefore \text{H.P. developed} = \frac{AV}{746}$$

Now manifestly, as the Characteristics of a dynamo are plotted to definite scales of volts and amperes, the power developed at any point on such a curve will be equal to the product of the co-ordinates of that point, and can therefore at once be seen.

If, however, curves of equal H.P. are, at the onset, drawn to the axes chosen, the above calculations will be avoided, for if the 2 H.P. curve cuts the Characteristic at a given point, then the power developed by the machine corresponding to the  $V$  and  $A$  of that point will be 2 H.P.

To determine these H.P. curves: Find several points such that the products of their co-ordinates = 746 Watts = 1 H.P. Thus, in Fig. 56 we have—

$$PQ \times QA = MN \times NW = GD \times DC = 746 \text{ Watts} = 1 \text{ H.P.}$$

similarly  $PR \times RW = KS \times SB = MF \times FC = 1492 \text{ Watts} = 2 \text{ H.P.}$

and  $XZ \times ZW = KT \times TY = 2238 \text{ Watts} = 3 \text{ H.P.}$

Then all points on the curve  $QND$  represent 1 H.P.

and " " "  $RSV$  " 2 H.P., and so on.

Intermediate values of H.P., such as 1.5 H.P., can be got by halving the distances between curves  $QND$  and  $RSV$ , etc.

These H.P. curves are simply rectangular hyperbolae if equal scales are used on the axes, but are distorted hyperbolae if the scales are unequal. Instead of H.P. they can equally well be drawn to represent kilowatts.

### (55) Determination of the External Characteristic of a Separately Excited Dynamo.

**Introduction.**—The type of machine under consideration as representing a *direct current* dynamo has little application in practice, but as representing an alternating current



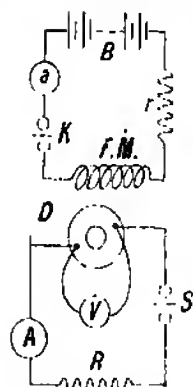


FIG. 57.

of E.M.F. can be obtained at any speed by suitably varying the exciting current ( $a$ ) by the rheostat ( $r$ ). The main disadvantage lies in having to provide an independent source of E.M.F. ( $B$ ) for exciting the field magnets ( $F.M.$ ).

The total E.M.F. is, as in the case of the magneto dynamo, given by the relation  $E = V + Ar_a$ , where  $A$  = the current flowing in the circuit at a terminal P.D. =  $V$  and  $r_a$  = the armature resistance.

The *external* and *total Characteristics* of the machine are found in *exactly* the same way as for the magneto dynamo, but at constant excitation as well as speed, and Fig. 57 shows the requisite apparatus *symbolically* and the connections of the same.

machine it has an extremely wide range of use. Such, however, we do not propose to discuss at this stage. Its utility in the first-named use lies in the fact that not merely can a far more powerful field be produced than is possible with any permanent steel magnets, which is of great value and, in fact, all-important in the generation of large E.M.F.s, but such a machine can be used with perfect safety in charging secondary cells, electroplating, etc., without the least fear of its polarity being changed should the back E.M.F. of the cells exceed that of the machine. A further advantage may be mentioned, viz. that a wide variation

## (56) Determination of the Internal Characteristic or Curve of Magnetization of a Separately Excited Dynamo.

**Introduction.**—In any dynamo, the P.D. across the brushes, i.e. armature, when no current flows in the external circuit, gives a measure, and is proportional to the magnetization of the field

magnets. If therefore the *field magnets* of any dynamo are *separately excited* by different currents from an independent source of E.M.F., the corresponding voltages across the brushes, *for constant speed*, will be approximately proportional to the inductions produced, if the machine is giving no current. The curve relating to exciting currents with E.M.F.s is termed the *internal Characteristic*, and it shows the region of saturation of the magnets, and also whether the eddy currents in the armature are producing any perceptible demagnetization of the field, and therefore shows the efficacy of the lamination of the armature core.

**Apparatus.**—Separately excited dynamo *D* to be tested; voltmeter *V*; exciting circuit comprising source of E.M.F. (*B*); ammeter *a*; switch *K*; rheostat (*r*) (p. 599); and field coils F.M.

**Observations.**—(1) Connect up as in Fig. 57, *omitting* the main current circuit there shown connected to the armature. Adjust the instruments to zero.

(2) Start *D* up to normal speed and with (*r*) large, close *S*, and take about ten different values of exciting current, rising by about equal increments from 0 to the maximum, and note the corresponding voltage *V* at each, the speed being constant throughout.

(3) Repeat 2 for a similar descending set of readings, and tabulate your results in a convenient manner.

(4) Plot the *internal Characteristic* having values of terminal voltage *V* (*x* to field flux) as ordinates, and exciting currents (*a*) (*x* to magnetizing force) as abscissae.

**Inferences.**—State clearly the meaning of the curve, and any inferences which can be drawn from the experimental results.

### (57) Relation between External Current and Exciting Current, at Constant Voltage, in a Separately Excited Dynamo, at Constant Speed.

**Introduction.**—If both the external and exciting currents are varied together in such a way that for a constant speed the terminal voltage is constant, then the curve showing the variation of one current with the other will show the increase of excitation that would be necessary to give constant voltage for varying external resistance at constant speed.

**Apparatus.**—Precisely that required for the preceding test, and in addition the main circuit comprising ammeter *A*; rheostat *R* (p. 606); and switch *S*.

**Observations.**—(1) Connect up as in Fig. 57, and adjust the instruments to zero. See that all lubricating cups in use feed properly.

(2) Start *D* up to the normal speed, and with a convenient excitation note the voltmeter reading *V*, which in future is to be kept constant as well as the speed.

(3) With *R* large close *S*, and take about ten different load currents *A*, rising by about equal increments from 0 to the maximum allowable, adjusting the exciting current to keep the volts constant. Note each pair of corresponding currents.

(4) Repeat 3 for a similar descending set of readings.

(5) Repeat 3 and 4 for a different speed but the same voltage, by suitably altering the initial excitation, and tabulate in a convenient form.

(6) Plot curves for each speed, for both ascending and descending readings having values of exciting current as ordinates and main currents as abscissae.

**Inferences.**—State clearly the practical value of the above tests, and explain the form of curve so obtained.

## (58) Determination of the External Characteristic of a Series Wound Dynamo.

**Introduction.**—In this type of machine the whole current developed at any time is employed for magnetizing the field magnets, but these are only wound with a comparatively small number of turns of thick wire to carry this main current.

The series machine is an extremely important one in practice, and will be found throughout the world in different parts. It is essentially employed as a *constant current* dynamo, usually developing a small current at a high E.M.F. The principal application is in the lighting of arc lamps in series, and as an electro-motor in the various branches of electric traction work. Regarding it first of all from a theoretical standpoint, there is only one circuit in operation, and hence but one current, in the case of a series

dynamo running an external circuit. Thus when this is broken there is no E.M.F., and the maximum E.M.F. is only obtained when close on the full load current is flowing.

The series dynamo possesses many peculiarities, the nature and effect of which, on practical working, it is all-important to be cognizant of. This investigation is best solved by obtaining the characteristic of the machine and studying it.

If  $r_s$  and  $r_a$  be the resistance of the series coils and armature respectively, and  $R$  that of the external circuit, then when the voltage across the terminals is  $V$ , the total E.M.F. generated

$$E = A (R + r_s + r_a)$$

where  $A$  = the current in the circuit; but  $V = AR$ ; hence

$$E = V + A (r_s + r_a).$$

**Apparatus.**—Series dynamo  $D$  to be tested; voltmeter  $V$ ; ammeter  $A$ ; switch  $S$ ; low resistance (variable) rheostat  $R$  (p. 606); tachometer.  $FM$  represents the field magnet (series) coils;  $TT$  represent the terminals of the dynamo.

**Observations.**—(1) Connect up as in Fig. 58, and adjust the instruments to zero, if necessary. See that all lubricating cups in use feed slowly and properly, and that the brushes are properly trimmed and the commutator smooth and clean.

(2) Start  $D$  up to its normal speed, and with  $S$  open note the reading on  $V$  (if any).

(3) With  $R$  large, close  $S$ , and take about ten values of current  $A$  (at constant speed), rising by about equal increments from 0 to the maximum permissible, and note the corresponding voltage  $V$  at each.

**Note.**—In starting, care must be taken not to decrease  $R$  too quickly, as the machine might suddenly build up on its residual magnetism, and a large rush of current ensue.

(4) Repeat 2 and 3 for a similar descending set of readings of  $V$  and  $A$ .

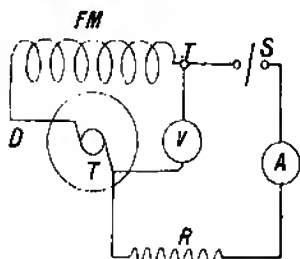


FIG. 58.

(5) Repeat 2—4 for speeds 20 % above and 50 % below normal respectively.

(6) Measure, by means of the Wheatstone Bridge, the resistance  $r_s$  of the series coils,  $r_a$  of the armature, and  $r_s + r_a$  of the whole machine while warm, supposing it to be not too small, and tabulate your results as follows—

NAME . . . . . Date . . . . .  
 Series Dynamo tested: No. . . . . Type . . . . . Maker . . . . . ( $v + r_s$ ) = . . .  
 Normal Voltage = . . . . . Amps = . . . . . Speed = . . . . . Resistance  $r_s$  = . . .  $r_a$  = . . .

Speed Revs. per min.	Ascending.		Descending.		Resistance of External Circuit = $\frac{V}{\text{mean } A}$ ohms.
	Terminal Volts ( $V$ ).	Amps. $A$ .	Terminal Volts ( $V$ ).	Amps. $A$ .	

(7) Plot the ascending and descending *external Characteristics* for each speed to the same pair of axes, having voltage ( $V$ ) as ordinates, and amps.  $A$  as abscissae in each case.

(8) From the above curves deduce, graphically, the *total Characteristics* on the same curve sheet in the manner described below (vide notation, p. 3).

(9) Plot the H.P. curves on the same sheet.

(10) Determine the *critical resistance* for this machine at each speed and also the *critical current*.

(11) Determine the internal Characteristic of the machine, and plot the results, having exciting currents as abscissae and armature E.M.F. as ordinates, to the same axes as the above curves.

(12) Plot the external resistance Characteristic having values of  $V$  as ordinates and resistance of the external circuit  $\frac{V}{A}$  in ohms as abscissae.

**Inferences.**—Explain the meaning of the curves very carefully. How can the effect of alteration of speed for one or more points on a Characteristic be corrected for? Why does the total Characteristic not droop so much as the external at the higher currents?

### Graphical Determination of the Total Characteristic from the External One in a Series Wound Dynamo.

Take two co-ordinate axes meeting in the point  $O$  of which the ordinates represent voltage and the abscissae current in amperes. Let  $x$  be the external Characteristic curve of the series dynamo.

Take any point  $Q$  on the abscissa representing any current  $OQ$  and set off on the ordinate a line  $QP$  to represent  $OQ \times (r_a + r_s)$  volts. Join  $OP$ , which therefore gives the rate of fall of potential down the armature and series coils combined, i. e. down the whole machine, or we have  $\tan \angle POQ = (r_a + r_s)$ . Now take any point  $a'$  in the curve  $x$  and through it draw an ordinate  $a'b'$  cutting  $OP$  and  $OQ$  in  $b$  and  $a$  respectively; set off  $a'b'$  as shown =  $ab$ , whence  $b'$  is a point on the total Characteristic. Repeat this operation for some ten different points along

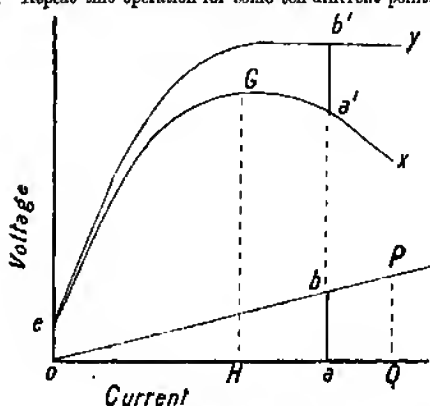


FIG. 58.

$x$  and finally obtain the total Characteristic  $y$  of the machine at the particular speed in question, Fig. 59.

If the curves start at some point  $c$  other than the origin  $O$ , then  $Oc$  is the E.M.F. at that speed due to residual magnetism in the field magnets when the external circuit is open, as in observation 2 above;  $Oc$  will be greater the greater the hardness and retentivity of the iron in the magnets.

If the curves  $x$  and  $y$  are much separated, it shows that the resistance of the machine, i. e.  $\tan \angle POQ$ , is too great, and therefore that it cannot be very efficient. Again, the summit  $G$  of the curve  $x$  shows for what output ( $GH \times HO$  Watts) and current  $OH$  the armature is magnetically saturated, and the drooping of the part  $Gx$  gives an idea as to the demagnetizing action of the

armature on the field. It is greater in dynamos in which the magnets are relatively less powerful than the armature, and is greatest in those machines in which the armature core is more nearly saturated than those of the field magnets.

### Graphical Determination of Critical Resistance at a Given Speed for a Series Wound Dynamo.

Let the curve  $OC$  be, say, the total characteristic of the machine for a given speed. Then the total circuit resistance

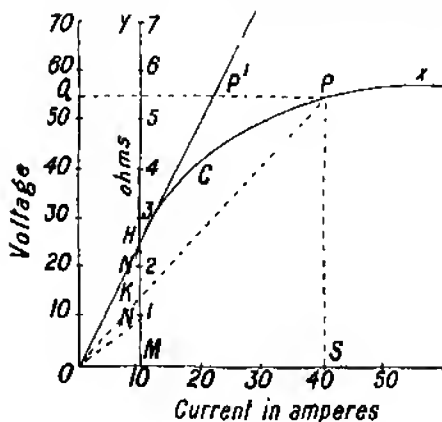


FIG. 60.

( $R + r_a + r_s$ ) corresponding to any point  $P$  can at once be found if the resistance line  $y$  is known, and which is found as follows—

Let  $N$  = point of intersection of the two axes 10, Fig. 60.

Then joining  $ON$  we have  $\tan \angle NOM = \frac{NM}{OM} = \frac{V}{A} = R = \frac{10}{10} = 1$ .

Hence  $N$  is a point representing 1 ohm.

Similarly  $N'$  being the point of intersection of the 20 volt axis and 10 ampere one, will represent  $\frac{V}{A} = \frac{20}{10} = 2$  ohms, and so on.

Thus the whole resistance line  $yM$  is obtained.

Now to obtain the circuit resistance for the point  $P$ , draw its co-ordinates  $PQ$  and  $PS$  and join  $OP$ .

$$\text{Then } \tan POS = \frac{PS}{OS} = \frac{V}{A} = \frac{55.0}{40} = 1.375 \text{ ohms,}$$

but  $MK = 1.375$ . Hence the resistance of the circuit ( $R + r_a + r_s$ ) is given by the point of intersection  $K$  of the join of  $P$  to  $O$ , and the resistance line  $My$ .

If then  $P$  approaches the origin  $O$  just so close that  $OP$  coincides with  $OP'$  and is practically a tangent to the curve (2), then its point of intersection with  $My$  gives the *critical circuit resistance*, above which the series dynamo will not excite.

This point is  $H$  and corresponds to 2.60 ohms on the resistance line. Thus for this speed the machine will not work if ( $R + r_a + r_s$ ) is greater than 2.6 ohms. For this instance the ordinates represent *total E.M.F.* of course, but if they were terminal volts and  $Ox$  the external characteristic, then  $MH$  would = the critical *external* resistance  $R$ .

### (59) Determination of the Internal Characteristic or Curve of Magnetization of a Series Wound Dynamo.

This is obtained in precisely the same manner as that in the case of the separately excited machine (p. 148), and consequently the mode of procedure will not be repeated. The curve should be plotted to the same axes as the ordinary Characteristics when the relative positions will form a measure of the armature reaction on the field.

### (60) Determination of the External Characteristic of a Shunt Wound Dynamo.

**Introduction.**—In the type of machine under consideration only a fraction of the full load current generated is employed for the purpose of magnetizing the field magnets, the winding of the coils of which consists of a large number of turns of small



gauge wire, possessing a comparatively large resistance. This shunt winding is connected directly across the brushes of the dynamo. Shunt dynamos possess a region of approximately constant potential, the falling off in this latter being mainly due to armature resistance.

This type of generator is an extremely important one and its sphere of application very large.

The performance and qualities of such a machine can best be investigated by means of its Characteristics. Regarding the shunt dynamo from a theoretical standpoint, suppose that  $A_s$ ,  $A$ , and  $I$  are the currents flowing through the armature, shunt, and external circuit whose resistances are respectively  $r_a$ ,  $r_s$ , and  $R$ , then we have  $A_a = A + A_s$ , since the armature current splits up through shunt and external circuits.

Now since we are dealing with two parallel circuits and one common potential difference, we have, that the terminal voltage  $V = IR = A_s r_s$ , and the parallel resistance of shunt and external circuit is

$$\frac{R r_s}{R + r_s}.$$

$$\text{Hence} \quad E = A_a \left( r_a + \frac{R r_s}{R + r_s} \right) = A_s r_s + E,$$

or by substituting for  $A_a$  its value  $A + A_s$  and reducing we get

$$E = V r_s \left\{ \frac{1}{R} + \frac{1}{r_s} + \frac{1}{r_a} \right\}.$$

**Apparatus.**—Shunt dynamo  $D$  to be tested, of which  $FM$

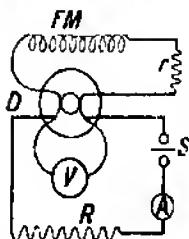


FIG. 61.

represents its field coils in series with a high resistance rheostat  $r$  (Fig. 209); voltmeter  $V$ ; ammeter  $A$ ; main variable rheostat  $R$  (p. 806); switch  $S$ ; tachometer.

**Observations.**—(1) Connect up as in Fig. 61, and adjust the instruments to zero if necessary. See that all lubricating cups in use feed properly.

(2) Start  $D$  up to its normal speed, and with  $S$  open vary  $r$  so as to produce normal excitation, then note the value of  $V$ .

(3) With  $R$  large, close  $S$  and take about ten different values

of current rising by about equal increments from 0 to the maximum. Note the voltage  $V$  at each and the current  $A$ , the speed being kept constant at the above value.

(4) Repeat 2 and 3 for a similar descending set of readings.

(5) Repeat 2-4 for speeds 30% above and 50% below normal respectively.

(6) Measure, by means of the Wheatstone Bridge, the resistance  $r_s$  of the shunt coils (warm), and by the "Potential Difference" method, the resistance  $r_a$  of the armature if very low, and tabulate your results as follows—

NAME . . .				DATE . . .		
Shunt Dynamo tested: No. . . .		Type . . .		Maker . . .		
Normal: volts . . .	Amps. . .	Speed . . .	Resistance $r_s$ = . . .	$r_a$ = . . .		
Speed Revs. per Minute.	Ascending.		Descending.		Resistance of External Circuit = $\frac{1000 V}{\text{mean } A}$ ohms.	
	Terminal Volts $V$ .	Amps. $A$ .	Terminal Volts ( $V$ ).	Amps. ( $A$ ).		

(7) Plot the ascending and descending *external Characteristics* for each speed on the same curve sheet, having values of  $V$  as ordinates and  $A$  as abscissae.

(8) From these deduce, by means of the following graphical construction, the *total Characteristics* on the same curve sheet.

(9) Plot the H.P. curves to the same axes also.

(10) Plot the external resistance Characteristic, having values of  $V$  as ordinates and resistance of the external circuit  $\frac{V}{A}$  ohms as abscissae.

(11) Determine the *critical resistance* of the machine for each speed and also the *critical current*.

**Inferences.**—State clearly all that you can deduce from your experimental results, explaining carefully the meaning of the shape of the curves.

### Graphical Determination of the Total Characteristic from the External Curve in a Shunt Wound Dynamo.

Referring to Fig. 62: let  $x$  be the external Characteristic. Take any point  $Q$  in the axis of abscissae representing any

current  $OQ$ , and from it set off  $QR = OQ \times r_a$  volts; join  $OR$ , which therefore gives the fall of potential in the armature, we also have  $\tan. ROQ = \frac{RQ}{OQ} = r_a$ .

Again, take any point  $T$  on the ordinates representing any voltage  $OT$  at the shunt terminals, and from  $T$  set off  $TS = \frac{OT}{r_s}$

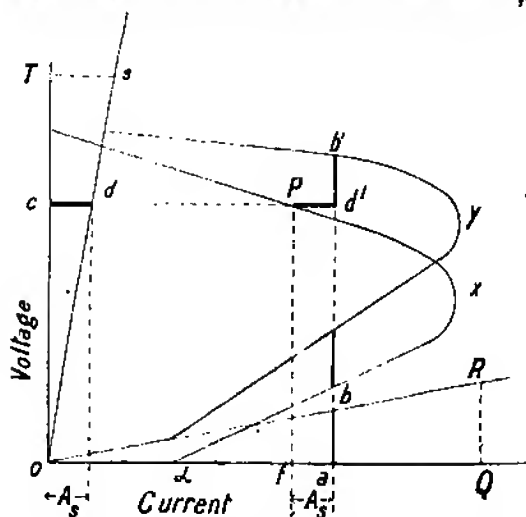


FIG. 62.

amperes; join  $OS$ , which therefore gives the current taken by the shunt coils at different voltages, and we have

$$\tan. SOQ = \frac{OT}{ST} = r_s$$

Now take any point  $P$  in  $x$ , and draw its co-ordinates  $Pc$  and  $Pf$  of which  $Pc$  cuts  $OS$  in  $d$ . Then  $cd =$  shunt current  $= A_s$  and  $cP =$  external current  $A$ . If now  $cP$  is produced to  $d'$  so that  $Pd' = cd$ , then the total armature current  $A_a = A + A_s = cP + Pd'$ .

Now draw an ordinate through  $d'$  cutting  $OR$  and  $OQ$  in  $b$  and  $a$  respectively. Then  $ab =$  loss of volts in armature due to total

current  $A_a = eI'$ , consequently setting off  $d'b' = ab$  we get  $b'$  a point in the total Characteristic which in a shunt dynamo gives the relation between total armature current  $A_a = (I + A_s)$  and total E.M.F.  $E = (V + A_s r_a)$ . On repeating this operation for a number of points such as  $P$  on  $x$  we are finally able to draw the total Characteristic ( $y$ ).

The working part of the curve is that at the top down to the sharp bend on the extreme right.

The critical external resistance  $R = \tan. \alpha$  for this speed, and the machine will only work providing  $R$  is greater than  $\tan. \alpha$ .

The lower or straight portion of the curves is the unstable part. Thus it will be seen that a shunt dynamo would give a nearly constant voltage for a given speed and variable external resistance, if it were not for the armature resistance.

## (61) Determination of the Internal Characteristic or Curve of Magnetization of a Shunt Wound Dynamo.

**Introduction.**—The internal Characteristic of a shunt dynamo is similar in shape to the total Characteristic of a series dynamo, and is a curve showing the relation between exciting or shunt current and the E.M.F. across the brushes for open external circuit. Since, however, the shunt current is so small that its passage through the armature would not cause any appreciable reaction or demagnetization, the shunt may be excited from the brushes and the armature allowed to give this small current, instead of disconnecting the shunt unit separately exciting it from an independent source. When the dimensions of the magnetic circuit of the machine are known, scales of the axes can be marked in air-gap flux density as ordinates, and amp. turns per pole as abscissae.

**Apparatus.**—Shunt dynamo; variable high resistance  $r$  capable of carrying the shunt current (p. 599); low reading ammeter ( $a$ ); switch  $S$ ; voltmeter  $V$ .

**Observations.**—(1) Connect the shunt coils of the dynamo in series with  $r$ ,  $a$  and  $S$  across the brushes and  $V$  also across them, and adjust the instruments to zero.

(2) Take an ascending and also a descending set of readings

of  $V$  and  $a$  (at constant speed, say the normal) by varying  $r$ , and tabulate the results in a convenient manner.

(3) Plot the internal Characteristic having voltages  $V$  ( $\propto$  to magnetic field flux) as ordinates and shunt currents ( $a$ ) ( $\propto$  to magnetizing force) as abscissae in both ascending and descending readings.

**Inferences.**—Carefully point out the meaning of the curves so obtained.

### (62) Determination of the External Characteristic of a Compound Wound Dynamo.

**Introduction.**—The type of machine under consideration is a combination of a series and shunt dynamo, so far as the field arrangements go, i.e. its field magnets are wound with both series and shunt coils.

The compound dynamo is a *self-regulating* machine for *constant terminal voltage* (at constant speed), independent of variations of external current. The principle of the self-regulating property is as follows:—As the external current increases in the case of a shunt dynamo the lost volts due to armature resistance and demagnetizing reaction of the armature in the field reduces the effective magnetism of the field magnets, but this increase of main current causes an increase in the field magnetism due to the series coils, which can be made to just counteract the diminution due to the lost volts, at *one definite constant speed*, thereby producing constant voltage at the terminals of the machine.

There are two possible methods of connecting the shunt coils to the machine, and which are shown in Fig. 63 symbolically, where I. represents what is called "*Long Shunt*," and II. that termed "*Short Shunt*."  $T_1 T_2$  are in each case the terminals of the dynamo, and as seen in the first case the shunt (*sh*) is across the extreme ends of armature and series coils (*ac*), i.e. across  $T_1 T_2$ , while in the second case it is across the brushes alone. A careful study of the dynamo with each method of connection will show which is the most desirable arrangement to use in any particular case. This, together with the investigation of the performance, etc., while working, can best be obtained by means of the Characteristics of the dynamo.

**Apparatus.**—Compound wound dynamo  $D$  to be tested; switch  $S$ ; voltmeter  $V$ ; ammeter  $A$ ; rheostat  $R$  (p. 606); tachometer.

#### LONG SHUNT.

**Observations.**—(1) Connect up as in Fig. 63 (I), and adjust the instruments to zero if necessary. See that all lubricating caps feed slowly and properly.

(2) Start  $D$  up to its normal speed, and when excited note the reading on  $V$ .

(3) With  $R$  large close  $S$ , and take about ten different values of current  $A$  rising by about  $\approx$  increments from 0 to the

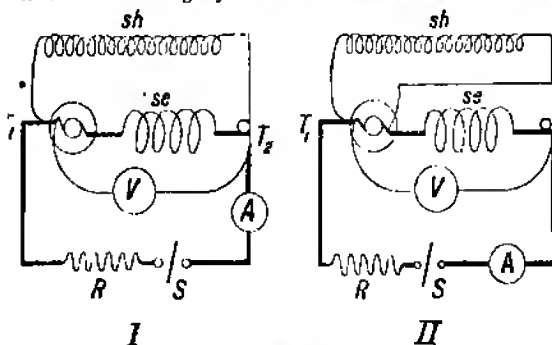


FIG. 63.

maximum allowable. Note the voltage  $V$  at each, the speed being constant at the above normal value.

(4) Repeat 2 and 3 for a similar descending set of observations.

(5) Repeat 2-4 for speeds 20% above and 50% under normal respectively for constant excitation in each case in the shunt coils.

(6) Measure by means of a Wheatstone Bridge the resistance  $r_a$  of the shunt, and by the "Potential Difference" method (p. 84) that of the armature  $r_a$  and series coils  $r_{sc}$ .

(7) Disconnect either coil in turn and repeat the above obs. 2-6 with the remaining coil, and so obtain the external Characteristic of the dynamo for each winding separately.

**Note.**—In doing this with  $sh$  connected alone, obtain the *same* initial voltage  $V$  as when running compound.

Tabulate all your results as follows—

Name . . . Date . . .  
Compound Dyn. no. tested: No. . . . Type . . . Make: . . .  
Normal Voltage . . . Amps. . . . Speed . . . Resistance  $r_a$  . . .  $r_{se}$  . . .  $r_{sh}$  . . .

Winding used.	Speed Revs. per min.	Ascending.		Descending.		Resistance of External Circuit = mean $V$ obsd. mean $A$
		Terminal Volts ( $V$ ).	Amps. ( $A$ )	Terminal Volts ( $V$ ).	Amps. ( $A$ )	

(8) Plot the *external Characteristics* for each speed, and both ascending and descending observations, having voltages  $V$  as ordinates and currents  $A$  as abscissae.

(9) From these deduce graphically, as described below, the *total Characteristics*, drawing them on the same sheet of paper. (For notation, see p. 3.)

(10) Plot the H.P. curves to the same axes also.

(11) Plot the external resistance Characteristic having values of  $V$  as ordinates and resistance of the external circuit  $\frac{V}{A}$  in ohms as abscissae.

**Inferences.**—State carefully all that can be inferred from your results, and explain the meaning of the various curves.

### Graphical Determination of the Total Characteristic from the External one, in a Compound Wound Dynamo.

LONG SHUNT.

Referring to Fig. 61, let  $x$  be the external Characteristic. Take any point  $Q$  in the abscissae representing any external current  $OQ$ , and set off from  $Q$  on the ordinates  $QR = OQ (r_a + r_{se})$ , whence  $\tan. R'Q = (r_a + r_{se})$ . Again, taking any point  $T$  representing any voltage  $OT$  at the shunt terminals, set off from  $T$  a line  $TS = \frac{OT}{r_{sh}}$  whence  $\tan. SOQ = r_{sh}$ .

Now take any point  $P$  in  $x$  and draw its co-ordinates  $PC$  and  $Pn$ , then the intercept  $Cd$  between  $OT'$  and  $OS$  = shunt current at this voltage  $Pn$ . As in the case of the pure shunt machine make  $Pd' = Cd$ , and draw an ordinate  $d'a$  through  $d'$  cutting  $OR$  and  $OQ$  in  $b$  and  $a$ .

Then making  $d'b' = ab$ , we get  $b'$  to be a point on the total Characteristic ( $y$ ). Repeating this process for several points, such as  $P$  along ( $x$ ), we finally get the curve  $y$  showing the relation between total armature current  $A_a$ , which =  $A + A_s$ , and total E.M.F.  $E$ , which =  $V + A_a(r_a + r_s)$ , where in Fig. 64  $On = A$ ,  $na = A_s = cd$ ,

$$\therefore On = On + na = A + A_s$$

$$\therefore ab = On(r_a + r_s) = A_a(r_a + r_s).$$

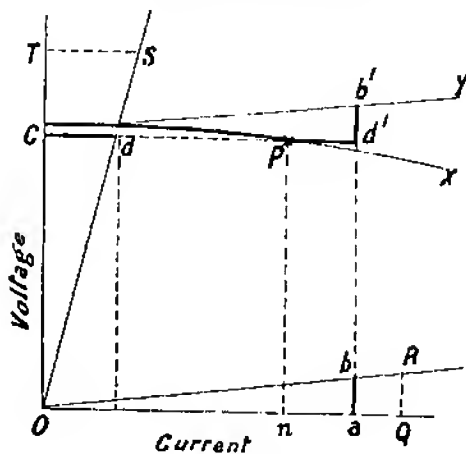


FIG. 64.

### (63) Determination of the External Characteristic of a Compound Wound Dynamo.

#### SHORT SHUNT.

As the mode of procedure is precisely the same as in the case of the corresponding long shunt test, this latter will not be



repeated here, and must be referred to both for apparatus, which is the same in both cases, and for the diagram of connections which is shown in Fig. 63 (II.).

### Graphical Determination of the Total Characteristic from the Internal one in a Compound Wound Dynamo.

### SHOUT SHUNT.

Referring to Fig. 65, let  $x$  be the external Characteristic. As

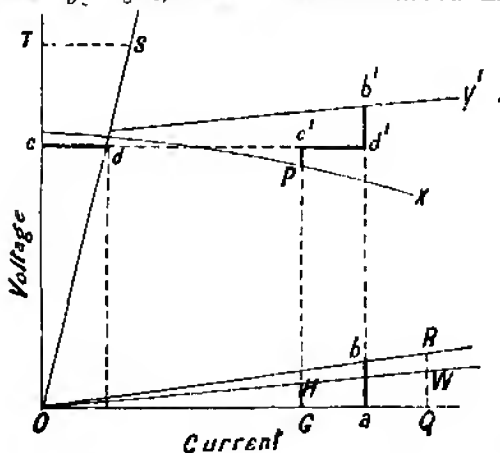


Fig. 65.

in the last case take any current  $OQ$  and set off  $QW = OQ \times r_s$  and  $QR = OQ \times r_a$  and join  $OR$ ,  $OW$ .

Obtain  $OS$  as before, and let  $P$  = any point on the curve ( $x$ ). From  $P$  draw  $Pc' = GI$ , and from  $c'$  draw  $c'd' = cd$ ; lastly, make  $d'b' = ab$  and  $b'$  is a point on the total Characteristic  $y$ , thus  $y$  is easily obtained. By reference to Fig. 65 it will be seen that the total R.M.F.  $E = V + A_{\phi_{\text{pa}}} + A_{\phi_{\text{sa}}}$ , while the total current in the armature  $A_g = A + A_{\phi_{\text{sa}}}$ , or in this Fig.—

$$ab' = P'G + GH + ab = V + \Delta r_{\Delta} + \Delta_{\sigma} \sigma_0$$

and

$$O_2 = OC + C_2 = A + A_{Sh}$$

### (64) Determination of the Separate Field Magnet Windings for Truly Compound- ing a Dynamo.

**Introduction.**—This is a practical method of experimentally determining the number of amp.-turns of excitation to be supplied by both the series and the shunt coils in a compound machine without having to calculate them in the ordinary way from data pertaining to the magnetic circuit. The method forms an exceedingly instructive one for use in a laboratory, in illustrating theoretical principles, but it is essentially a *works* method, and has the advantages that the amp.-turns are determined under full load *working* conditions, i.e. when the armature is exerting its maximum demagnetizing influence on the field, and furthermore that since the whole machine is already constructed except for these coils, any errors in the lengths and sections of the various parts of the magnetic circuit and in their estimated permeabilities are nullified.

The conditions for automatic self-regulation by compound winding are, firstly, that with the external circuit *open*, i.e. no current through the series coils, the shunt winding must alone produce, at the given speed, the full specified voltage of the machine. Secondly, that on full load the series or winding must supply such an extra amount of magnetization, due to the full-load current in its coils, as will maintain the same specified voltage of the dynamo. There are obviously two modes of procedure differing slightly from one another and depending on circumstances at hand, namely, (1) to compound a machine *given* its carcass ready built up and the armature ready wound; (2) to compound a shunt machine by finding the necessary series turns to be added. Consider the former conditions first.

**Apparatus.**—In addition to the machine in question—a voltmeter  $V$ ; switches  $S$  and  $S_1$ ; ammeters  $A$  and  $a$ ; rheostats  $R$  (p. 606) and  $r$  (p. 599); source of E.M.F. ( $B$ ) for excitation, either battery or other dynamo, etc.

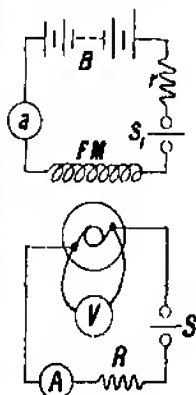


FIG. 65.

**Determinations.**—(1) Take a *suitable* field frame of the type of machine specified, i. e. one that previous experience shows to be of sufficient size for the work, also a *suitable* ready-wound armature, wound with a suitable number of turns of a gauge sufficient to take the specified full-load current of the machine at an orthodox current density in the coils.

(2) Wind the field magnet limbs uniformly with a few temporary turns  $F$  (known) of thick wire or lead, and connect up as in Fig. 66, adjusting the instruments to zero.

(3) Run the armature at the specified speed ( $n$ ) revolutions per minute, and with  $S$  open close  $S_1$ , adjusting the exciting current ( $a$ ) by means of  $r$  until  $V$  reads the specified voltage. Then  $aF$  = amp.-turns to be supplied by the shunt coils alone.

(4) Now close  $S$ , and obtain the full-load current  $A$ , of specification, at the same speed ( $n$ ) above; again adjust  $r$  so that  $V$  again reads the same specified voltage as before. If  $a_1$  now = the exciting current, then  $a_1 F$  = amp.-turns to be supplied by (series + shunt) together; hence  $(a_1 - a)F$  = amp.-turns to be supplied by series coils alone at that voltage  $V$  and speed ( $n$ ) or number of series turns =  $\frac{(a_1 - a)F}{A}$ .

Such a gauge of wire is then chosen for the shunt coils, that with a shunt current of, say, 2% of  $A$  (the main one) the shunt resistance =  $\frac{V}{2A} = 50 \cdot \frac{V}{A}$  ohms and the amp.-turns =  $aF$ .

100

If we are dealing with case 2, in which it is desired to convert a shunt machine into a compound one, it should be remembered that such an alteration is only possible when the field magnets are not magnetically saturated.

The mode of procedure is then practically the same as before, and is as follows—

Disconnect the shunt and separately excite it, so as to reproduce the same terminal voltage (at full load) as the shunt (by itself) gave with the armature on open circuit.

If then the total number of shunt coil turns =  $T$  and the shunt current rose from the original value ( $a$ ) to the new value ( $a_1$ ) in order to keep up the same voltage at full load as on open circuit, then  $(a_1 - a)T$  = amp.-turns to be supplied by series coils;

and if the full-load armature current is  $A$ , then number of series turns =  $\frac{(a_1 - a)T}{A}$ , the speed being constant all the time.

It will be obvious that the method serves to determine the windings necessary to *over compound*, the exciting current at full load being raised until the excess over the normal voltage = the drop of volts in the mains at that current.

### (65) Determination of the Speed and E.M.F. at which a Dynamo truly Compounds.

**Introduction.**—The present test of course relates to a compound wound dynamo which is already built and finished. It has been previously mentioned that a given machine can only compound truly and exactly to give *constant voltage* for wide variations of external current, at one particular definite speed. This is owing to the different alterations which a definite variation of speed produces on the series and shunt Characteristics of the machine. Thus, if after a machine is built and completely finished it is found that the compounding is not quite correct at the speed used in the calculations, which could easily be the case, then the speed would form a means of final adjustment and the mode of procedure would be as follows—

(a) With the machine connected so as to self-excite in the usual way, place an external circuit consisting of an ammeter  $A$ , rheostat  $R$ , and switch  $S$  in series with the machine terminals and a voltmeter  $V$  across them.

(b) Run the dynamo at the speed employed in the design, and take first the open-circuit volts  $V$  and then that at some 4 or 5 loads between 0 and the maximum.

(c) If on plotting these observations the Characteristic thus formed droops, the series coils are too weak in their effect and the speed should be raised a little, another set of readings being taken.

In this way a speed will be found by trial such that the curve is a *horizontal* straight line or nearly straight between 0 and full load. The speed and volts at the terminals now are the values required for exact compounding.

### (66) Variation of the E.M.F. of an Alternator with Speed at Constant Excitation.

**Introduction.**—The present test is an important one, as showing not merely the effect of alteration of speed on the E.M.F. developed by an alternator for constant exciting current, but also whether the demagnetizing effect of the armature on the field, due to eddy currents generated in it, is producing a perceptible effect, and if so the speed at which this effect begins to assert itself most forcibly. The eddy current loss varies as the square of the speed for constant magnetic field, so that the results of the test will give a measure of the adequacy of the lamination of the iron parts of the machine.

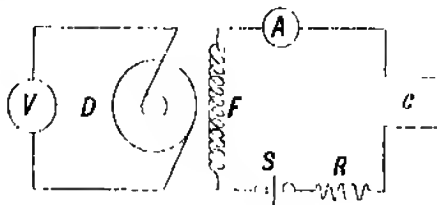


FIG. 67.

**Apparatus.**—Alternator *D* to be tested; alternating current voltmeter *V*; speed indicator and means of driving *D* at any suitable speed. For the exciting circuit, in addition to the field coils *F* of the alternator—a variable rheostat *R* (p. 599); switch *S*; ammeter *A*; exciting E.M.F. *e* consisting either of the requisite E.M.F. from a secondary battery or auxiliary direct current supply, etc.

**N.B.**—Since in this test the speed is variable, and consequently also the periodicity of the current, the voltmeter *V* should be either a "hot wire" or "electrostatic" instrument, these being the only two types of meters which are unaffected by the variation of periodicity.

**Observation.**—(1) Connect up as in Fig. 67, and adjust the pointers of the instruments to zero. See that all lubricating pumps in use feed properly and slowly, and then start the alternator.

(2) Close *S*, and adjust the exciting current on *A* to the normal for the machine by altering *R*, and keep it constant; then adjust the speed so as to obtain the lowest readable voltage on *V*; note simultaneously the speed and voltage *V*.

(3) Repeat 2 for about ten different speeds, rising by about equal increments from the above value to the highest allowable (a) at the same constant normal excitation, (b) at a constant value 50% loss.

(4) Repeat 2 and 3 for the same constant exciting currents with constant full load armature current in each case respectively, and tabulate your results as follows—

Name . . .	Type . . .	Date . . .
Alternator tested: No . . .	Armature . . .	Maker . . .
Normal Full-Load Voltage . . .		Speed . . .
Normal Exciting Current . . .		

Speed Revs. per min.	Voltage (terminal) <i>V</i>	Exciting Current <i>A</i> Amperes

(5) Plot curves having E.M.F. (i.e. terminal voltage) as ordinates and speed as abscissae for each excitation both on no-load and full-load to the same pair of axes.

**Inferences.**—Carefully state all that can be inferred from the results of the above test, and point out their bearing on the design of alternators.

### (67) Variation of the E.M.F. of an Alternator with Excitation at Constant Speed (Magnetization or Open-Circuit Characteristic).

**Introduction.**—This test is an important one, in that it shows the degree of approximate magnetic saturation of the field magnets at any excitation, and in conjunction with the short-

circuit characteristic will give a predetermination of the regulation of an alternator for terminal E.M.F. on load. If the magnetization of its field magnets is carried too close to the point of saturation, then manifestly it will require large variations of exciting current to produce comparatively small variations in the E.M.F. of the machine. This, it need hardly be pointed out, is undesirable, and would cause a most insensitive form of regulation. Again, it will be apparent that, if no demagnetizing action of the armature on the field is going on, the exciting (i.e. magnetizing) current will represent the magnetizing force and form a measure of it. This in turn will create a certain magnetic field and magnetization, and in this field the armature rotates, or as in the inductor form of alternator this field is made to change from zero to full and back to zero, and in so doing cuts the stationary armature conductors. But the E.M.F. generated is  $\propto$  rate of change of this field, and at constant speed to the field strength itself. Hence the E.M.F. is a measure of the magnetic field or induction excited, providing there is no armature reaction. Thus the present test will give us approximately the curve of magnetization of the alternator field magnets, but it must be carefully remembered that this is only approximate and provided there is no armature reaction on the field due to eddy currents in the armature, which should not occur when the machine is running on no load.

**Apparatus.**—Precisely the same as that used in the preceding test.

**Observation.**—(1) Connect up exactly as indicated in Fig. 67, and adjust the instruments to zero. See that all lubricating cups feed properly and slowly, and then start the alternator.

(2) Adjust the speed of the alternator to the normal value for that machine, and keep it constant. Close *S* and adjust the exciting current (by varying *R*), so as to obtain the lowest readable voltage on *V*. Note this simultaneously with the exciting current and speed.

(3) Repeat 2 for about ten different exciting currents, rising from the preceding amount to the maximum allowable, the speed being constant at the above value throughout.

(4) Take a similar descending set of observations as in 3.

(5) Repeat 2 and 3 for (constant) speeds 50% below, and if possible 20% above *normal*, and tabulate your results as follows —

Name . . .		Date . . .	
Alternator tested, No . . .		Type . . .	Maker . . .
Normal Voltage . . .		Current . . .	Speed . . .
Normal Exciting Current = . . .			
Speed Revs. per min.	Exciting Current A. Amps.		Terminal Voltage V.
	Ascending	Descending	Descending

(6) Plot curves for each speed to the same axes having volts as ordinates and exciting currents as abscissae, both for ascending and descending readings.

**Inferences.**—State very clearly all that can be inferred from your results, and point out their bearing on the design of alternators.

### (68) Magnetization Curve of an Alternator on Full Load—Non-Inductive and Inductive.

**Introduction.**—While the "no-load magnetization" curve or "open circuit" Characteristic of both an alternator and D.C. dynamo take the same general form, the curve which, as we have seen, relates terminal voltage of armature with excitation current is different on full load, and in the case of an alternator depends on the nature of the external load, i.e. whether inductive or non-inductive. This difference is due to the loss of terminal voltage on load caused by the *armature resistance, reactance, and reaction* of the armature when delivering current; though only resistance causes loss of power. Armature reaction is responsible for distorting and either strengthening or weakening the main magnetic field in the air gap, and is due to armature current and depends on the power factor of the external circuit, while armature reactance, due to the self-induction of the armature conductors,



causes the current to lag behind the induced voltage, though in phase with the terminal voltage, and is unaffected by the power factor of the external circuit. The magnetization curve on full load, when compared with that on no load, affords valuable information needed for the design of a field regulator for the alternator to give any particular degree of sensitiveness.

**Apparatus.**—Precisely that given for Test No. 70.

**Observations.**—(1) Connect up as in Fig. 69, levelling and adjusting such instruments as need it to zero. See that the lubricating arrangements are working properly on starting up the motor alternator, which should be the same as that used in obtaining the "open circuit" Characteristic of Test No. 67.

(2) With a variable *non-inductive* resistance  $R$  connected for absorbing the output, and with  $R$  and  $r$  full in, adjust the speed of the alternator to its normal value and maintain this constant throughout by field regulation on the driving motor. Now close  $S_1$  and  $S_2$  and reduce  $R$  until the alternator gives full-load current on  $A$ , then note the readings of  $V$ ,  $A$ , and (a) at *constant normal speed* for this and a series of exciting currents ( $\alpha$ ) decreasing by about equal amounts to the lowest possible, the armature current  $A$  being kept constant by reducing  $R$ .

(3) With a variable *inductive* resistance for  $R$ —composed either of an adjustable choking coil in series or parallel with adjustable non-inductive resistance, or of a synchronous motor, the excitation and loading of which can be varied (*vide* p. 305), and the addition of a wattmeter for measuring the power absorbed in  $R$ , Fig. 69. Repeat obs. 2 for constant power factors  $\cos \phi$  of, say, 0.9, 0.8, etc., leading and lagging if possible, and tabulate all your results as follows—

Alternator tested; No. = . . .

Type . . .

Maker . . .

Full load; Volts = . . .

Amperes = . . .

Speed = . . .

Nature of load— Ind. or Non-Ind.	Speed.	Armature Amperes, $A$ .	Exciting Amperes, $\alpha$ .	Volts $V$ .	Watts $W$ .	Power Factor or $\cos \phi = \frac{W}{AV}$

(4) Plot (from obs. 2 and 3) curves of full-load magnetization to the same axes, having volts  $V$  as ordinates with exciting currents ( $\alpha$ ) as abscissae.

(5) For comparison replot the "no-load" magnetization curve obtained in Test No. 67 for the same alternator on the above curve sheet.

**Inferences.**—What can you deduce from the results of the above test, and how can the range of field regulating resistance be obtained for maintaining constant voltage between 0 and full load on any particular power factor of circuit? What excitation is necessary to send full-load short-circuit current through the armature at normal speed?

### (69) Determination of the Short-Circuit Characteristic of an Alternator.

**Introduction.**—This characteristic, which is really the magnetization curve of the alternator on short circuit, differs from that obtained in Experiment 70, in that in conjunction with the "open" circuit characteristic of the machine, p. 163, it forms a means of predetermining the "voltage drop," i.e. the regulation of any alternator at different external loads and power factors. In this way large alternators may be tested while giving full-load current although requiring very little power to drive them.

**Apparatus.**—Precisely that detailed for Experiment 70, the resistance  $R$  being capable of variation and of being short circuited.

**Observations.**—(1) Connect up precisely as in Fig. 69, and adjust the pointers of such instruments as require it, to zero. See that all lubricators in use feed slowly and properly.

(2) Start the alternator up to *normal speed* and close  $S$ , noting the readings of  $V$  and  $A$  (if any) with  $R$  cut out to short circuit.

(3) With  $(r)$  full in, close  $(a)$ , and adjust the exciting current  $(a)$  (by varying  $r$ ) to some small value that will cause  $A$  to read about  $\frac{1}{10}$ th of the full load current of the alternator. Now read all the instruments. Next open  $S$  and again take readings, the speed being kept constant at the *normal value* throughout.

(4) Close  $S$  again, and increase  $A$  by about another  $\frac{1}{10}$ th, by suitably increasing the exciting current  $(a)$ . Then note the

readings of all the instruments. Next open  $S$  and again take readings, the speed being constant at normal value throughout.

(5) Repeat (1) for a series of values of  $A$  up to 20% above full load value.

(6) To determine the effect of speed variation on the short-circuit current, run the alternator up to max. safe speed and raise its excitation until full load, or 20% over full load, current is obtained. Note this current, the speed, excitation and voltage and also for some ten different speeds, decreasing by about equal amounts to the lowest convenient at *constant excitation*, and tabulate in the following manner.

**Note.**—To avoid the risk of damaging the armature of the machine, especially if a large one, the series resistance  $R$  should all be cut into circuit before closing and again before opening  $S$ , and should be cut out to short circuit just before taking instrument readings.

Alternator: No. . . . . Type . . . . . Maker . . . . .  
 Full Load Output . . . . . Amps. . . . . Volts . . . . . revs. per min.  
 " " Excitation = . . . . . Amps. . . . . Frequency = . . . . . per sec.  
 Resistance (watts) of Armature + Ammeter and Leads  $R = \dots$  ohms.  
 Percentage Allowance  $K$  (if any) = . . . . .  
 Total Equivalent Resistance  $R_T = (R + KR) = \dots$  ohms.

Speed (con- stant).	Terminal Armature Volts.		Short Circuit Armature Current $A_s$	Exciting Current $a$	Effective Volts for Ohmic Resist. $AR_T$	Inductive Voltage Drop $\sqrt{A_s^2 - (AR_T)^2}$ $= E_s$
	Short Circuit $R_A$	Open Circuit $E$				

(7) Plot the "short-circuit characteristic" having values of  $(A_s)$  as ordinates and  $(a)$  as abscissae, and also the curve having  $A$  as ordinates with speed as abscissae.

**Inferences.**—State all that can be deduced from the results of the test.

### Determination of the "Voltage Drop" of an Alternator for any given load and circuit Power Factor.

From the results of the above test and with the aid of a simple graphical construction, it is easy to find approximately the voltage drop corresponding to any load current and power factor. Thus—

From any point  $O$  in any straight line  $XY$  set off  $OE$ , to a convenient scale, to represent any desired "open circuit" voltage of the alternator and at such an angle  $\theta$  to the current line  $XY$ , that the power factor ( $\cos. \theta$ ) of the circuit has the desired value for the particular load current (= short circuit current  $A$ ) assumed.

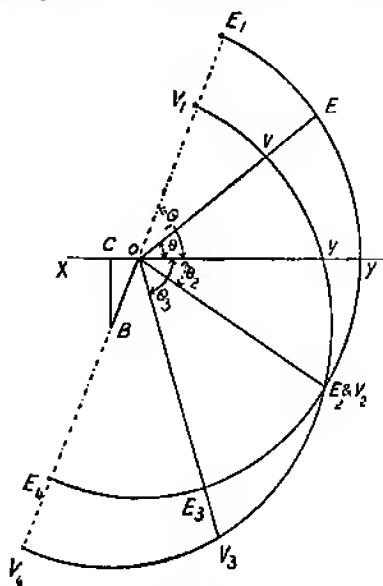


FIG. 68.

With centre  $O$  and radius  $OE$  draw the semi-circle  $E_1YE_4$ . Next set off along  $XY$ , the line  $OC = AR$ , the armature drop and allowance ( $R$ ) for eddy current loss, corresponding to the same main current  $A$ .

**Note.**—In small, slow speed machines, the power lost due to eddy currents in armature core and pole pieces is small, and the effect of this on the voltage drop is also small compared with the term  $AR$  and can be neglected. When, however, the effect is too

large to neglect as in large machines the term  $AR$  can be increased by a certain percentage ( $K$ ) depending on the form of alternator and the speed, (as dictated by experience with this type of machine or by experiment) to allow for the eddy current effect. Since the term  $AR_r$  is small compared with  $E$ , the error introduced in the value of the inductive drop  $E_r$  through estimating the percentage increase of  $AR$  wrongly, is very small.

From  $C$  draw  $CB$  perpendicular to  $XY$  and  $=$  the short-circuit inductive or idle voltage drop  $E_r$  due to the self-induction of the armature and loss of voltage due to armature reaction. Join  $OB$  which therefore  $=$  the open circuit voltage  $E$ , which is necessary to overcome the self-induction and resistance of the armature and leads, for the short-circuit current  $A$  assumed.  $OCB$  is therefore the right-angled triangle of E.M.F.'s on short circuit and the angle  $COB =$  the angle of lag between current and voltage on short circuit. Now with centre  $B$  and radius  $OB$  draw the semi-circle  $V_1VV_2$ . Then  $OV =$  terminal voltage of the machine and  $VE$  the voltage drop for the main circuit current  $A$  and circuit power factor  $\cos \theta$ .  $OV$  and  $VE$  can similarly at once be found for any other value of power factor with the same main current  $A$  from the same diagram. A new diagram must, however, be constructed in a similar manner for a different current  $A$  in order to obtain the terminal volts such as  $OV$  and drop such as  $VE$  for this new current. Some interesting cases are now obvious, namely—

*For main current lagging behind the voltage, i. e. self-induction predominating in the main circuit.*

(1) For main circuit power factors corresponding to an angle  $\theta_1 = COB$ , when  $OE$  takes the position  $OE_1$  in line with  $BO$ , the terminal voltage  $OV_1 =$  minimum and the inductive drop  $V_1E_1 =$  maximum.

(2) For a non-inductive main circuit,  $\theta = 0$  and the terminal voltage  $OY$  is in phase, and coincides in sense, with the main current, but will differ from the resultant voltage  $OB$  by a little more than  $90^\circ$ .

*For main current leading in front of voltage, i. e. capacity predominating in the main circuit.*

(3) For the negative angle  $\theta_2$ , terminal voltage  $OV_2 =$  open circuit voltage  $OE_2$  and there is no inductive drop.

(4) For greater "loads," the terminal voltage is greater than the open circuit voltage, e.g. for a  $-90^\circ$  angle  $\theta_2$  the terminal voltage  $= QV_2$  and open circuit voltage  $OE_2$ , maximum values of these quantities being reached at  $OV_4$  and  $OE_4$  where the maximum  $-90^\circ$  inductive drop  $= E_4 V_4$ .

### (70) Determination of the External Characteristic of an Alternating Current Generator.

**Introduction.**—This test is for the purpose of experimentally determining, for different speeds and excitations, the relation

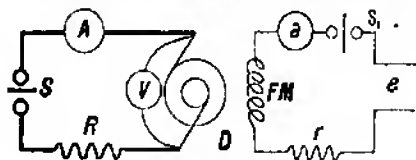


FIG. 69.

between external current and the terminal voltage producing it. By means of the *Characteristic curve*, as it is called, so obtained by plotting the observations, it can be seen at a glance whether the alternator possesses any serious defects. Its performance when running on some particular circuit at some particular speed and excitation is also easily discernible therefrom.

**Apparatus.**—Alternator  $D$  to be tested; switch  $S$ ; alternating ammeter  $A$ ; and voltmeter  $V$ ; non-inductive resistance  $R$ , which should preferably consist of either a bank of glow-lamps (p. 598), carbon (p. 597) or water rheostat, all of which are non-inductive; in circuit with the exciting coils  $F$ —a rheostat  $r$  (p. 599); switch  $S_1$ , ammeter ( $a$ ); and source of direct current  $e$  from secondary cells or otherwise; speed indicator. Wattmeter  $W$  (not shown) for measuring the true watts absorbed in  $R$  when this is inductive.

**Observations.**—(1) Connect up as in Fig. 69, and adjust the pointers of all the instruments to zero, if necessary.

(2) Start the alternator up, seeing that all lubricating arrangements be used properly. Close  $S_0$ , adjusting both the speed and excitation to the normal for that machine.

(3) With this excitation and speed constant, take, by varying  $R$ , a set of readings for about ten different values of external current between 0 and the maximum permissible, differing by about equal amounts, and note the simultaneous readings of  $V$  and  $A$ .

(4) Repeat (3) with the same normal excitation, but for constant speed 50% below normal.

(5) Repeat (3) and (4) for a different excitation, say, 50% lower than normal, and tabulate all results in the accompanying form.

(6) Measure the resistance of the armature, while warm, by the "Potential Difference" method (see p. 84), or by the ammeter voltmeter method, p. 86.

Name . . . . . Date . . . . .  
 Alternator tested: No. . . . . Type . . . . . Maker . . . . . Periods per Revol.  $K = \dots$   
 Normal Volts . . . . . Amps . . . . . Speed . . . . .  $n = 2\pi \times$  frequency.  
 Armature Self-induction  $L = \dots$  Henry Ohmic Resistance Warm  $r_a = \dots$

Speed Revs. per min.	Exciting Current (a) Amper.	Volts. $V$ .	Amps. $A$ .	Watts. $W$ .	App. Watts $A \times V$	Power Factor $\cos \phi = \frac{W}{AV}$	Induction.	
							Resistance, $r_a$ .	E.M.F., $E$ .

(7) Plot the *external Characteristic* curves for each speed and excitation having terminal volts  $V$  as ordinates and current  $A$  through armature and external circuit as abscissa, in each case (see p. 3 on curve plotting) using the same pair of axes and curve sheet.

(8) Deduce the *total Characteristic* curves of the machine from the "external" ones in 7 above by means of the graphical method given below.

**Inferences.**—Very carefully state all that you can infer from your experimental results, and show in what way the above curves indicate the performance of the alternator, and give an idea as to the goodness of the efficiency.

### Graphical Determination of the Total Characteristic of an Alternator from the External Characteristic.

The *total Characteristic* of an electrical generator is the curve showing the relation between the *total E.M.F.* in volts generated by the machine and the *total armature current* in amperes.

#### ANALYTICAL TREATMENT.

Referring now to the preceding diagram (Fig. 59), let  $L$  = self induction of the armature in henries —

$r_a$  = ohmic resistance of the armature in ohms.

$R$  = ohmic resistance of the external circuit, assumed to be non-inductive.

$p$  = angular velocity of the alternating current =  $2\pi n$ .

$n$  = frequency or periodicity in  $\sim$  per sec.

If then a current  $A$  flows in the external circuit at a terminal voltage  $V$  and  $E$  = total E.M.F. of the generator,

$$\text{then } A = \frac{E}{\sqrt{L^2 p^2 + (R + r_a)^2}} \quad \text{but } V = AR;$$

$$\text{hence } E = \sqrt{L^2 p^2 A^2 + (R + r_a)^2 A^2} = \sqrt{L^2 p^2 A^2 + (Ar_a + V)^2}.$$

Consequently we see that the total E.M.F. in volts generated by the alternator is represented by the hypotenuse of a right-angled triangle, of which the other two sides represent  $LpA$ —the inductive E.M.F. necessary to overcome that of self-induction, and  $(Ar_a + V)$ —the effective E.M.F. necessary to send the current  $A$  through the ohmic resistance  $(R + r_a)$ .

If  $K$  = number of periods per revolution of the armature, then  $\frac{KN}{60} = (n)$ , the frequency in  $\sim$  per sec.; whence  $p = 2\pi \frac{KN}{60}$ , where  $N$  = number of revolutions per minute the armature is making.

Having thus obtained an expression for the total E.M.F. of the machine analytically, we will now proceed to deduce it graphically from our external Characteristic.



## GRAPHICAL TREATMENT.

Let  $xy$  represent the external Characteristic plotted to the rectangular axes  $OT'$  and  $OS$ , of which the former represents voltage and the latter current, respectively. (See Fig. 70.)

From the point  $O$  or origin draw the straight line  $OQ$  such that  $\tan \angle OSQ = r_a$ , and also draw the straight line  $OP$  such that  $\tan \angle POS = I_p$  for the particular speed at which  $xy$  is taken.

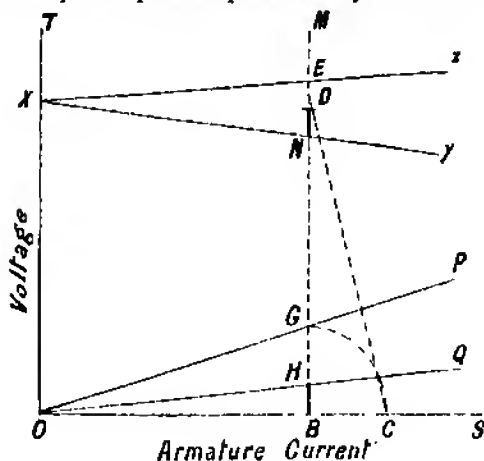


FIG. 70.

Take any point  $N$  on the external Characteristic  $xy$  and through it draw an ordinate  $MNB$  cutting  $OP$ ,  $OQ$  and  $OS$  in the points  $G$ ,  $H$  and  $B$ , respectively.

Set off  $ND = BH$  and  $BC = BG$  and join  $DC$ , which therefore  $= E$ . Lastly, make  $BE = CD$ .

Then  $E$  is a point on the total Characteristic required. If this construction is repeated for several more points, such as  $N$  on  $xy$ , we finally obtain a series of points such as  $E$ , and on drawing a mean curve through them all we obtain the required total Characteristic  $ax$ . In this construction it will be noticed that—

$BN =$  the terminal voltage ( $V$ ).

$BQ = BG$  = the inductive E.M.F. ( $LpA$ ).

$BH = ND$  = the effective E.M.F. ( $Ar_a$ ).

$\therefore DBC$  is consequently a right-angled triangle, and

$$\text{hence } DC = E = \sqrt{BC^2 + BD^2} = \sqrt{(LpA)^2 + (Ar_a + V)^2}.$$

Probably a better mode of procedure and one *not* requiring the use of a protractor in obtaining the correct angle at which to set off  $OP$  and  $OQ$  is to first take any point  $N$  on  $xy$ , obtain the ordinate  $MNB$  and set off  $BG$  = the current  $OB \times Lp$ , also  $BH = OB \times r_a$ , then joining these points  $H$  and  $G$  to  $O$  we get the required lines  $OHQ$  and  $OGP$  respectively, after which proceed as above.

### (71) Determination of the External Characteristic of an Alternator for different circuit Power Factors.

**Introduction.**—The circuits which have to be supplied from alternators, in ordinary commercial work, are invariably inductive, possessing either self-induction or capacity or both. As the inductiveness of the circuit affects the terminal voltage of an alternator,—self-induction causing the characteristic to fall and capacity causing it to rise, it is important to be able to determine the characteristic for any power factor of the circuit, whether the current lags or leads with respect to the voltage.

*Lagging currents* can easily be obtained with any power factor by suitable combinations of self-induction and ohmic resistance, as for example by carbon rheostats and continuously variable choking coils or dimmers.

*Leading currents* can be obtained by inserting along with, say carbon rheostats (1) a number of condensers possessing considerable capacity, (2) a long length of concentric cable, (3) a *synchronous* a.c. motor with fields excited so that the back E.M.F. of the motor exceeds the voltage of the alternator. This is by far the most convenient method, for any load can easily be taken from the alternator by either braking the motor pulley or making it drive a d.c. dynamo at various loads. It can be shown that over-excited synchronous motors cause a leading current to flow in the circuit supplying them, and hence produce the same effect as 1 and 3 above. By adjusting the excitation of such a motor any lead can be obtained within limits.

Where the only means available for obtaining *lagging* power factors is by varying combinations of self-induction and ohmic resistance, or for obtaining *leading* P.F.s is by varying combinations of capacity and ohmic resistance, it is a very tedious process to try and take a series of readings of output current with terminal voltage at constant P.F. This is obvious since it entails varying the inductive and non-inductive sections of the load circuit so that they always bear the same ratio to one another, as only this will keep  $\cos \phi$  constant in value, since the P.F. or  $\cos \phi = \frac{\text{ohmic resistance}}{\text{impedance}}$ . In other words, trial combinations would have to be repeatedly made and the value of  $\frac{W}{AV}$  worked out for each, to see if it had the desired value for  $\cos \phi$ . For this reason the following method is better, and is applicable to any appliance capable of giving an electrical output which has to be absorbed in an inductive circuit. Since the output obviously comprises (amps  $A \times$  volts  $V$ ), both of which are variable simultaneously between 0 and full load, and  $A = \frac{V}{\text{impedance}}$  or  $V = A \times \text{impedance}$ , it follows that  $A$  will be constant if  $V$  and the impedance vary in the same proportion, while  $V$  will be constant if  $A$  and the impedance vary in inverse proportion. Thus if the inductive portion of the load circuit is adjusted to max. value, and the non-inductive portion in series or parallel with it (whichever is found most suitable) is varied, it is possible to obtain different values of  $A$  corresponding to different values of  $\cos \phi$  at constant  $V$ , or different values of  $V$  corresponding to different values of  $\cos \phi$  at constant  $A$ , and a curve can be plotted between  $\cos \phi$  as ordinates and the variable as abscissae. If, now, the inductive portion is made less inductive and the non-inductive part again varied, a new value will be obtained for the constant and a new series of values of  $\cos \phi$  and the variable obtained, which will give a second curve with  $\cos \phi$  as ordinate and the variable as abscissae.

Repeating the process for some five or six degrees of inductiveness, giving therefore as many values of the constant and corresponding curves between  $\cos \phi$  and the variable, we can utilize these *auxiliary curves* to obtain the same number of

curves between  $V$  and  $A$  each at any desired constant power factor ( $\cos \phi$ ) within the limits produced by the range in degree of inductiveness used. As an example—Suppose  $A$  is the constant and  $V$  the variable with  $\cos \phi$ , and that six auxiliary curves, each obtained for, and marked with, the corresponding constant, are plotted on the same sheet. Now to obtain the curve between  $V$  and  $A$  at, say, 0.9 power factor: note the six points or voltages on the volt scale cut by the ordinates through the six points of intersection between the single horizontal line through the 0.9 mark on the  $\cos \phi$  scale and the six curves. Then the six voltage values so found, plotted against the six constant values of  $A$  marked on the respective curves, will give the desired relation between  $A$  and  $V$  at a constant power factor  $\cos \phi = 0.9$ .

Similarly, a curve between  $A$  and  $V$  could be drawn for  $\cos \phi = 0.8, 0.7, 0.6$ , etc.

**Apparatus.**—The same as that detailed for Test No. 70, except that the load resistance  $R$  must now comprise a variable self induction and variable non inductive resistance, and that a wattmeter  $W$  must be inserted so as to give the true watts absorbed in the whole circuit.

**Observations.**—(1) Connect up as in Fig. 69 with the slight modifications just mentioned. Level and adjust the pointers of any instruments needing it to zero, and see that the lubricating arrangements are in operation on starting up the machine.

(2) With  $S$  closed and with both *excitation* and *speed* adjusted to the normal value and maintained *constant*, vary the proportions of heavy self-induction and large ohmic resistance in the main circuit, so as to obtain some six different voltmeter and corresponding wattmeter readings for each of five different but constant alternator currents  $A$ , differing by about equal amounts between 0 and full load, the same value of main current to be obtained for each of the six readings of a set.

(3) Plot five curves one for each of the five constant values of main current, each having the terminal voltage of the alternator as abscissae and power factor (obtained by indicator or wattmeter and volt-amperes) as ordinates. Mark on each curve the constant main current at which it was obtained.

(4) Repeat obs. 2 and 3 so as to obtain a similar set of five curves for *leading currents* of the same magnitude as previously

used by varying the load on the synchronous motor and its excitation, and tabulate as in Test No. 70.

(5) Plot the external characteristic curves having volts as ordinates and currents as abscissæ for power factors differing by 0.1 at a time between 1.0 and the lowest obtained in the curves between voltage and power factor (3) to (4) above, each curve in (3) and (4) supplying one point only in each of the characteristic curves corresponding to the current and voltage, and the power factor for which the particular characteristic is plotted.

**Inferences.**—State clearly all that you can deduce from the results of your tests.

## (72) Variation of Exciting Current with the Armature Current of an Alternator to maintain Constant Terminal Voltage on Inductive and non-Inductive Loads.

**Introduction.**—This test is a direct measurement of the range of variation in both the resistance and current of the field regulator required to maintain constant terminal voltage for any range of load, and which can otherwise be deduced from a reference to the external and magnetization characteristics of the alternator when available.

**Apparatus.**—That detailed for Test No. 70, with the addition of an adjustable inductive resistance for combination with  $R$ .

**Observations.**—(1) Connect up, as in Fig. 69, with  $R$  non-inductive only at first and the wattmeter inserted as a check on the product  $A \times V$ . Level and adjust all instruments, which require it, to zero, and on starting up the motor alternator see that all lubricating arrangements are working properly.

(2) With the speed and terminal voltage each adjusted to the normal value and kept constant—the former by regulation at the driving source, and the latter by field regulation of the alternator—first note the value of exciting current ( $a$ ), on open main circuit, and then with  $S$  closed for each of a series of 8 or 10 armature currents,  $A$  rising by about equal increments to full load by adjusting the non-inductive resistance  $R$ , the

field regulation of the alternator being adjusted so as to keep  $V$  constant with the speed constant.

(3) With  $R$  now inductive, and the same value of speed and voltage as in obs. 2 maintained constant, adjust the inductive part to its maximum value and vary the non-inductive part so as to maintain the main current  $A$  constant at about quarter full-load value, the field current being correspondingly varied to keep  $V$  constant. Note the readings of  $A$ ,  $V$ ,  $W$ , and  $(a)$ .

(4) Repeat (3) for the same speed and voltage, but for constant values of  $A$  of about half, three quarters, or full load, and tabulate as in Test No. 70.

(5) Plot the four auxiliary curves (vide p. 182), having power factors,  $\cos. \phi = \frac{W}{AV}$ , as ordinates, with exciting current  $(a)$  as abscissae, for each of the four constant values of  $A$  respectively.

(6) By interpolation and transference, plot the desired relations between exciting currents  $(a)$  as ordinates, with main currents  $(A)$  as abscissae for non-inductive load (obs. 2), and for inductive load (obs. 3 and 4) at constant power factors of 0.9, 0.8, etc.

**Inferences.**—State clearly all that can be deduced from a study of the shape and relative dispositions of the curves in (6) above.

### (73) Determination of the Efficiency of an Alternator without running it on load.

**Introduction.**—The preceding method, although a direct one for obtaining the efficiency of any generator by measuring the H.P. absorbed in driving it and the output in the usual way, requires some type of transmission dynamometer and has therefore a limited application on account of the difficulty of measuring the large H.P.s in the case of large generators. While small alternators can be tested in this way, the method of driving the generator by an electromotor (preferably direct coupled) having a known efficiency-load curve, is more accurate, and also has a much more extended application in range of power. The power supplied to the motor  $\times$  by its efficiency at that load = the power taken to drive the generator.

Both methods are however costly of application in the case of the larger generators and an arrangement similar to Swinburne's Test No. 82 would obviously be preferable in many ways.

Further, if while absorbing (from an outside supply) only a small fraction of its rated full-load output, the armature of an alternator carries full load current at normal excitation, both the losses and temperature rise can be determined at an economical cost of energy consumed in the test.

From the fundamental principle that, in any transforming device

$$\text{output} = \text{input} - \text{total internal loss}$$

we see that if the losses can be obtained in the various portions of the alternator, the input and efficiency are at once deducible and that the method is applicable to any size of machine, however large.

The total internal loss in an alternator is made up of—

(a) The total copper loss  $W_c$  in the armature windings, thus—

If  $C_a$  = the current per phase of armature winding

and  $r_a$  = the resistance per phase „ „ „

the total copper loss  $W_c$  in the armature of  $n$ —single-phase alternator =  $C_a^2 r_a$ ; of a two-phase alternator =  $2C_a^2 r_a$ ; and of a three-phase alternator =  $3C_a^2 r_a$ .

(b) The total power absorbed in excitation  $W_x$ . Thus if  $C_x$  = the exciting current employed at a pressure of  $V_x$  volts, then  $W_x = C_x V_x$ .

(c) The total power absorbed in mechanical friction  $W_{MF}$  and made up of—windage, bearing friction, brush friction.

(d) The total power spent in magnetic friction made up of—hysteresis and eddy currents in field and armature core  $W_{LP}$ .

Then the total internal loss  $W_i = W_c + W_x + W_{MF} + W_{LP}$ .

The last two losses, which may be termed the stray power, may be determined experimentally at no load by running the alternator as a synchronous motor, light and unloaded, and measuring the power absorbed by wattmeter.

**Apparatus.**—Alternator  $D$  to be tested, capable of being driven at no load and normal speed by some outside source of power. This might preferably be its direct-coupled exciter, if

there is one, and provided that, when used as a motor, it is powerful enough, or, in the absence of this, a direct-coupled motor  $M$  of known efficiency. The necessary switches; a wattmeter having a range up to say 5% of the full load of the alternator; an ammeter  $A$ ; and a voltmeter  $V$  in the case of single-phase alternators and of two- and three-phase alternators with equally-balanced phases. Two of each type of instrument will be needed for two- and three-phase machines out of balance.

**Observations.**—(1) Connect up as shown in Fig. 71, adjusting each of the instruments as need it and assuming the alternator  $D$  to be a three-phase machine for instance. See that all lubricators feed properly.

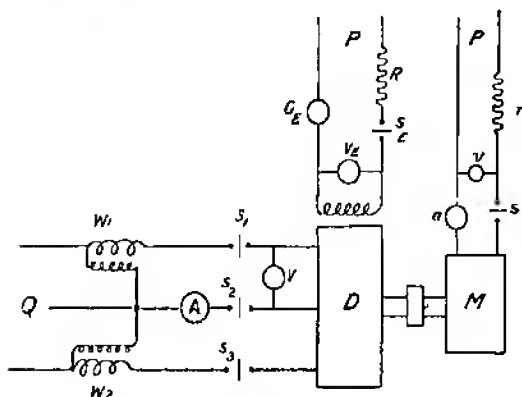


FIG. 71.

(2) To run  $D$  as a synchronous motor from some a.c. supply  $Q$  of the normal voltage  $V$  and frequency developed by  $D$ . First start up  $D$  to its normal speed by means of  $M$  and adjust its exciting current  $C_E$  so that its terminal voltage  $V$  = that of the supply  $Q$ .  $S_1$ ,  $S_2$ ,  $S_3$  being open, but  $S_1$  shorted by a wire and  $S_3$  by two synchronizing lamps (see p. 441) not shown, close this three-throw switch at the instant when the lamps are out and at



once open  $S$ . The alternator  $D$  will now continue to run as a synchronous motor at normal speed, frequency and voltage.

(3) With  $D$  running as just mentioned, adjust its exciting current  $C_x$  by the rheostat  $R$  so that a minimum intake current  $A$  is obtained and hence maximum power factor, and note the wattmeter readings  $W_1$  and  $W_2$  and all the other instruments and speed.

$$\text{Then } W_1 + W_2 - 3A^2r_a = W_{MV} + W_{IR}$$

These losses are approximately constant for all loads, slightly increasing as the load increases due to change of induction through increase of excitation for voltage regulation, and to armature reaction in the normal operation of the alternator.

(4) With the *same normal supply frequency* as in obs. 2, and *same excitation* as found in obs. (3), increase the supply voltage  $V$  (by means of the field excitation of the supply  $G$ ) so as to obtain a series of supply currents  $A$  rising by about equal increments from the value found in obs. (3) to full load, and note the readings of  $A$ ,  $V$  and  $W_1$ ,  $W_2$  at each.

**Note.**—The synchronous motor  $D$  will run throughout obs. (4) at constant normal speed but at a decreasing power factor, as was shown in Test No. 106, and since the excitation is constant at normal value, the losses ( $W_L + W_{MV} + W_{IR}$ ) as measured by  $W_1$  and  $W_2$  will be the same as for the machine used as an alternator when giving the same current loads from its armature. The excitation loss  $W_x$  is also known, and the total internal loss at all loads can therefore at once be found and the efficiency  $\Sigma$  obtained from the relation—

$$\Sigma = \frac{\text{output}}{\text{output} + \text{losses}}$$

The accuracy of the values of efficiency ( $\Sigma$ ) thus found will depend on the degree of accuracy with which the losses, in obs. 4, can be measured; this latter may not be high on account of the increasing inaccuracy of wattmeters on the lower power factors.

(5) If necessary, find the rise of temperature of the machine after a six hours' run on full-load or other desired condition.

Tabulate your results for the preceding test as follows—

Alternator: No. . . . . Type . . . . . Maker . . . . .  
 Full Load: Amps. = . . . . Volts = . . . . Speed = . . . . Frequency = . . . .  
 Resistance: Armature per phase  $r_a$  = . . . . Field = . . . .  
 Wattmeter Constants  $K_1$  = . . . .  $K_2$  = . . . .

[illegible]

Plot the efficiency-load curve of the machine considered as an alternator having values of efficiency  $\Sigma$  as ordinates, and values of  $\sqrt{3}AV$  (calculated for each value of  $A$  in the table but at normal voltage) as output at P.F. = 1.

The separation of the losses can be obtained in much the same way as that indicated in Test No. 77 for direct current machines by the use of the motor *M* in the following way—

(4) With  $S_1$ ,  $S_2$ ,  $S_3$  and  $S_4$  both open, run the alternator at its normal speed and note the readings ( $a_1, v_1$ ) of  $a$  and  $v$ . If  $y_1$  is the efficiency of  $M$  at this speed and load, then  $y_1 a_1 v_1 = W_{\text{me}}$  the power absorbed in mechanical frictions since with the fields of  $D$  unexcited there will be practically no iron losses.

(5) Next close  $S_x$  and adjust  $R$  so as to give normal full load exciting current. Vary  $r$  so as to obtain the same speed as before and note the readings  $a_2 v_2$  of  $a$  and  $v$ . If  $y_2$  = the efficiency of  $M$  at this load, then  $y_2 v_2 = W_{M2} + W_f$ , and hence the iron losses  $W_F = y_2 a_2 v_2 - y_1 a_1 v_1$ .

Having now obtained the iron and friction losses the efficiency can at once be deduced for all assumed loads.

Tabulate your results for Tests 4 and 5 as follows—

Electronics of Motor at Speed used: (at load $\alpha_1 \gamma_1$ ) $\gamma_1 = \dots$ ; (at load $\alpha_2 \gamma_2$ ) $\gamma_2 = \dots$				
Alternator Speed	Alternator unexcited.		Alternator Excited.	
	Reading of Ammeter (a) $\alpha_1$	Reading of Voltmeter (v) $\gamma_1$	Reading of Ammeter (a) $\alpha_2$	Reading of Voltmeter (v) $\gamma_2$
				Excitation Load Loss $\gamma_2$ = $\frac{W_{\text{exc}} + W_{\text{load}}}{\text{Power} = 2 \gamma_2 \gamma_1}$

The determination of the iron losses at any speed by the retardation method can be undertaken in alternators having sufficient inertia or momentum in their moving portions to prevent them slowing down to rest too quickly for readings of speed to be taken at intervals.

(6) With  $S_D$ ,  $S_B$ ,  $S_A$  and  $S_R$  both open, run  $D$  at normal speed by means of  $M$ . Then at a noted interval of time, the speed being at normal value, open  $S$  and note the speed by tachometer at, say,  $\frac{1}{4}$  minute intervals as the alternator  $D$  slows down to rest, the motor  $M$  being of course unexcited. The retardation in this test is due to  $W_{Mf}$ .

(7) Repeat (6) with  $\frac{1}{2}$ ,  $\frac{3}{4}$  and full load exciting currents  $C_R$  by varying  $R$ . The more rapid slowing down in this test is due to  $W_{Mf} + W_{IR}$ . Tabulate your results as follows—

Value of  $W_I + W_R = 3 A^2 r_a$  (from Exp. 3).

Alternator Unexcited.		Alternator Excited			Values of		Actual mean Power in Watts absorbed
Times $t_1, t_2, \dots$	Speeds $n_1, n_2, \dots$	Exciting Current $C_R$	Times $t_1, t_2, \dots$	Speeds $n_1, n_2, \dots$	$\frac{W_R}{I}$	Average speed $N = \frac{n_1 + n_2 + \dots}{\gamma}$	

Plot curves for 6 and 7 between speeds as ordinates and times as abscissae, and between  $\frac{W_R}{I}$  as ordinates and average speeds  $N$  as abscissae.

The rationale of the retardation method is as follows—

Let  $I$  = the moment of inertia of the rotating system in C.G.S. units, or, gramme-cm.<sup>2</sup> about the axis of rotation, and let  $W$  be its angular velocity in radius per sec. Then the kinetic energy of the whole system or energy of rotation  $K_R = \frac{1}{2} W^2$  ergs =  $\frac{1}{2} (2\pi n)^2 I$  where  $(n)$  = speed in revs. per second.

Hence the kinetic energy =  $\frac{1}{2} \left( \frac{2\pi n}{60} \right)^2 I \times 10^{-7}$

$$= 548 \cdot 10^{-12} n^2 I \text{ Joules or Watt seconds,}$$

where  $(n)$  is now in revs. per min.

If now  $(n)$  = the normal speed of the alternator at the instant  $t$  of opening  $s$  and  $n_1, n_2, n_3 \dots$  the successive speeds noted at times  $t_1, t_2, t_3 \dots$  from the instant  $(t)$  when slowing down commences,

Then the energy expended or work done in the first interval of time in overcoming resistance is proportional to

$$548 \times 10^{-12} I(n^2 - n_1^2)$$

and the mean power absorbed  $W_x = \frac{548 \times 10^{-12} I(n^2 - n_1^2)}{t - t_1}$  watts

at an average speed  $N = \frac{n + n_1}{2}$  revs. per min.

By plotting a curve between values of  $\frac{W_x}{I}$  for successive speeds and intervals as ordinates and the corresponding average speeds  $N$  for successive pairs of speeds as abscissae, we can get the loss at any speed, and that at *normal speed* by the point of intersection of the curve (produced backwards) with the full speed ordinate.

Note.—Since  $I$  is a constant but unknown quantity, the ordinates of the curve are the values of  $\frac{W_x}{I}$  and the ordinates do not therefore represent actual watts, but = watts  $\div$  a constant ( $I$ ).

From Observation 3, however, we know that this normal speed ordinate =  $W_1 + W_2 - 3A^2r_a$ , the total friction and iron losses. Hence the value in actual watts of any other ordinate corresponding to any other speed is at once found by simple proportion.

From the above data compile the following general table—

Alternator No. . . . . Type . . . . . Maker . . . . .  
Full Load: Amps. = . . . . . Volts  $V$  = . . . . . Speed = . . . . . Frequency = . . . . .  
Resistances: Armature per phase  $r_a$  = . . . . . Field  $r_f$  = . . . . .

Watts Output Watts Assumed C.	Watts Output $W_o = I^2 C$	Losses.				Total Watts $W_o + W_L$	Efficiency $\frac{W_o}{W_o + W_L} \times 100$
		Excitation $C_e V_a = W_a$	Armature $3 C_a^2 r_a = W_c$	Iron and Friction $W_{if} = W_{if}$ = W.	Total $W_L =$ $W_c + W_{if} + W_a$		

Plot the load-efficiency curve having efficiency as ordinate and  $W_o$  as abscissa.

### (74) Efficiency and Internal Loss Test of a Pair of Alternators (by the Hopkinson Principle).

**Introduction.**—The following method is available when two similar alternators, as nearly alike in output as possible, are obtainable. It is analogous to the Hopkinson test of a pair of D.C. dynamos, and has the double advantage that all the measurements are electrical ones; and also that while both alternators run under load conditions, so far as field and armature current is concerned, each is running at only a fraction of its full K.W. capacity, and consequently the power taken from the necessary outside supply is small, even in the case of the testing of large alternators. The method further lends itself most conveniently to the determination of the temperature rise of each machine under the same heating conditions as would obtain if each was run for, say, six hours at full-load

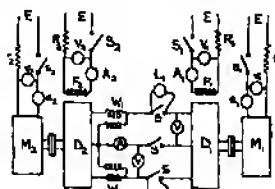


FIG. 72.

output, but with far greater economy in the cost of energy consumed from the outside supply.

The test can be carried out with the two alternators under one or other of two conditions, viz. (1) when they are not mechanically coupled together, or (2) when their shafts are in accurate alignment and rigidly coupled. In each case (a) the alternator to be used as a generator (say  $D_1$ ) must be either belted or (preferably) direct coupled to a small direct-current motor  $M_1$  having a known "efficiency-load" curve at the speed to be employed; (b) the second alternator  $D_2$  must be electrically connected to  $D_1$  and run as a synchronous motor from its supply; (c) an

additional driving source of power (which might be another D.C. motor  $M_2$ ) will be needed to run  $D_2$  into synchronism, and afterwards to be disconnected if possible. Now, although under condition (1) above, the power factor of the circuit between  $D_1$  and  $D_2$  will decrease as the circulating current increases, any error that might be introduced from this cause, and referred to in test No. 73, p. 188, is eliminated in the present test, as the losses are now measured in the D.C. circuit of  $M_1$  instead of being obtained from the readings of  $W_1$  and  $W_2$ .

Under condition (2) above, however, in which the shafts of  $D_1$  and  $D_2$  are rigidly coupled, the P.F. of the circulating circuit remains constant for all currents with any particular bolting of the half couplings. If this bolting can be varied, then each constant value of the P.F. can be varied from unity, when the half couplings are bolted so as to make the E.M.F.s of  $D_1$  and  $D_2$  differ by  $180^\circ$  in phase (i.e. when in direct opposition of phase), to zero, when one half coupling is bolted with an angular difference relatively to the other half coupling equal to the angular pitch of the alternator field. Throughout this range the alternator with the greater excitation will be acting as generator.

Obviously with the rigid coupling of condition (2), the two alternators must not only be similar in output and voltage, but must also give the same frequency at the same speed, whereas in condition (1) their frequencies can be different if necessity arises. Further, the general applicability of the present method is questionable, e.g. in condition (2) the alternator  $D_2$  must be coupled either (on the left) up to  $D_1$ , or (on the right) up to the other end of  $M_1$ , so that either  $D_1$  or  $M_1$  must have a shaft extension each end. On the other hand, the test under condition (1) will need a second driving motor  $M_2$ , which for the highest accuracy should be capable of disconnection from  $D_2$  after this is synchronized. These facilities may be obtainable in certain works, but seldom exist in a college laboratory.

**Apparatus.** That depicted in Fig. 72, where  $R_1R_2$  are field regulators for adjusting the exciting currents in the fields  $F_1F_2$  of  $D_1D_2$ .

$r_1r_2$  are starters or main circuit adjustable rheostats for the motors  $M_1M_2$ .

$L_1 L_2$  are synchronizing lamps made for voltages equal that per phase of the supply.

$E$  is a D.C. supply, and three-phase alternators are assumed for test as presenting slightly greater complication in connection and test than single or two-phase machines.

**Observations.**—(1) Connect up similarly to Fig. 72, but with any modifications which the facilities available in machines necessitate. Level and adjust to zero all instruments needing it, and on starting up see that all lubricating arrangements feed properly.

(2) With  $D_1$  running at normal voltage  $V$  and frequency, synchronize  $D_2$  by obtaining equal voltages as  $V.V.$ , and closing  $SSS$  at the moment when  $L_1 L_2$  are definitely out.  $M_3$  (if used) being disconnected electrically and mechanically, if the latter is possible.

(3) Next adjust  $R_2$  so as to make  $A$  a minimum for constant normal values of both  $V$  and the frequency.

Note the readings of all the instruments and the speeds of  $D_1$  and  $D_2$ .

Then the output of  $M_1$ , or power required to drive  $D_1$   
 $= \frac{a_1 v_1}{e}$  = the total internal running losses ( $W_C + W_{MF} + W_{IF}$ )  
 (see p. 186) in  $D_1$  and  $D_2$  together (excluding excitation losses in  $D_1 D_2$ ).

Where  $e$  = the efficiency of  $M_1$  at this load and speed (from curve),

$$\frac{a_1 v_1}{2e} = \text{the losses in either alternator.}$$

(4) Now reduce the excitation of  $D_2$  by the same amount as that of  $D_1$  is increased, so as to obtain a series of main circulating currents  $A$ , rising by about equal increments up to the full load current of the machines, and note the readings of all instruments at each value of current  $A$ . Then the increased

value of  $\frac{a_1 v_1}{2e}$  = the losses in either alternator at the respective current values  $A$ , where  $(e)$  has an increasing value at each load as taken from the efficiency-load curve of  $M_1$ . Adding half the total excitation loss, viz.  $\frac{1}{2}(A_1 V_1 + A_2 V_2)$ , to the above loss, we get the total internal loss  $W_L$  (p. 186) corresponding to each

of the current  $A_1$  and which will be practically those which would exist if either machine was supplying those currents as an alternator at the same speed and voltage. Tabulate all your results as follows:—

Alternator  $P_1$ : No = . . . Type . . . Maker . . . Armat. Res. per phase  $r_a$  = . . .  
Full Load: Amps = . . . Volts  $V_L$  = . . . Speed = . . . Frequency = . . .  
Field Res  $r_f$  = . . .  
Alternator  $D_2$ : No = . . . Type . . . Maker . . . Armat. Res. per phase  $r_a$  = . . .  
Full Load: Amps = . . . Volts  $V_L$  = . . . Speed = . . . Field Res  $r_f$  = . . .  
Wattmeter Constants  $K_1$  = . . .  $K_2$  = . . .  
Driving Motor  $M_1$ : No = . . . Full Load: Amps = . . . Volts = . . . Speed = . . .

[illegible]

(5) Plot the efficiency-load curve of either machine considered as an alternator having values of  $\Sigma$  as ordinates and values of load  $\sqrt{3}AI_s$  as abscissae.

**Inferences.**—Clearly state all that can be deduced from the results of the test.

**Note.**—If the wattmeters  $W_1$  and  $W_2$  (which are not really essential to this test, and only useful, if available, for observing and comparing certain quantities) are omitted, the eight columns in the table, necessitated by their use, can also be omitted.

### Determination of the Distribution of Potential round the Commutator of a Dynamo.

**General Remarks.**—On considering the action which occurs with a single turn of wire on a coreless armature as it rotates at



a uniform rate through one revolution we find that, starting from a position  $0^\circ$ , which may be termed the zero position, when its plane is perpendicular to the direction of the lines of force due to the fixed field  $NS$  (Fig. 73), its E.M.F. is 0, because it is slipping through and not cutting these lines. When it gets to  $90^\circ$ , the rate at which it cuts the lines is a maximum, and this decreases round to  $180^\circ$  again, when the E.M.F. is 0, and after then the effect is simply repeated. The zero position  $nn$  is the neutral axis or diameter of commutation for *no current* in the coil or armature, while  $RR$  is the line of resultant magnetization at right angles to

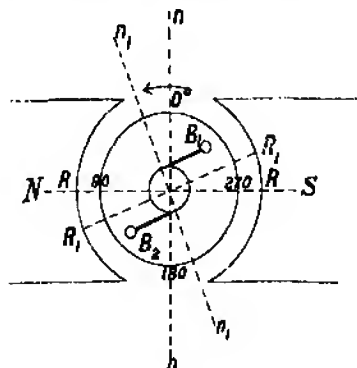


FIG. 73.

$nn$ . In fact, the E.M.F. generated in the coil at any position is approximately  $\propto$  sine of the angle of rotation from  $nn$ , and, as we have seen, is zero at  $0^\circ$  and  $180^\circ$ , and a maximum at  $90^\circ$  and  $270^\circ$ . If the coil be wound on an iron core, carries a current, and is made to rotate, it will react on the fixed field  $NS$ , causing a distortion of this latter, so that  $n_1n_1$  will now be the neutral axis or diameter of commutation and  $R_1R_1$  the line of resultant magnetization. In other words, the resultant field produced by that due to the armature and field  $NS$  will be forced round through an angle  $ROK_1$  in the direction of motion, and will cause the brushes to advance through an equal angle  $non_1$  to the

position  $n_1n_2$ , which angle is called the "angle of Lead" of the brushes.

• If now, the circular path of the coil, which we will assume for the moment not wound on an iron core, is developed out into a straight line  $AC$ , and the sine of the angular position from  $O$  (i. e.  $A$ ), Fig. 74 I., plotted on the ordinates at each such position, the curve  $APBQC$  will be obtained, showing the variation of E.M.F. with angular position in one revolution. Thus  $A$  and  $C$  correspond to  $0^\circ$  or position  $nn$  (Fig. 73) when the

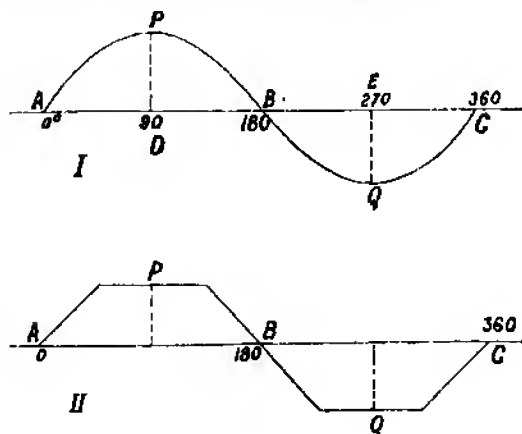


FIG. 74.

E.M.F. is nought, while  $PD$  and  $QE$  correspond to  $90^\circ$  and  $270^\circ$ , or position  $RR$  when E.M.F. = maximum. This curve is called a sine curve, and it possesses the uniform shape shown in Fig. 74 I.

Now in an ordinary iron core armature the E.M.F. of each coil fluctuates in a manner similar to that shown in Fig. 74 I. in a bipolar machine, and to that shown in Fig. 74 II. in a multipolar machine, but the commutator commutes such E.M.F.s so as to develop an E.M.F. at the brushes perfectly continuous in direction.

Considering the armature as a whole, the line  $nn$  or  $n_1n_2$ , i. e. the brushes of the machine divide the armature coils into two

halves, which are in parallel with one another, now each half consists of separate coils in series with one another, each giving a certain but different E.M.F. depending on their position relatively to  $\theta$  or  $m$ . These E.M.F.s being in series are added together in each half and the two summational E.M.F.s put in parallel. Thus the E.M.F. between the brushes = sum of E.M.F.s round one half of armature between those brushes. Consequently, as we proceed from, say, the negative main brush, the E.M.F. (if we could sample it) round either half increases up to the other main brush, first slowly, then rapidly, and finally slowly again when nearing the maximum point.

From the preceding remarks it will be evident that two investigations can be made on the E.M.F. of armature coils—(a) that of any one coil in different positions of a revolution; (b) the way in which the E.M.F. varies as we proceed from one brush right round the armature.

There are many methods of performing these investigations, and amongst those most easy of application in practice may be mentioned Prof. S. P. Thompson's, Mr. Morley's, and Mr. Swinburne's, and these we will now consider in detail.

In Thompson's method of operating investigation (a) above, the E.M.F. of a single section on the armature can be sampled at different points in the revolution. The arrangement consists of two flat metal strips or brushes  $b_1 b_2$  (Fig. 75) fixed to a piece of wood at a distance apart equal to the width between two consecutive commutator bars. A voltmeter is connected across  $b_1 b_2$ , which therefore measures the E.M.F. of a single section of the armature winding which is passing through the particular position of the field, corresponding to the position of the contacts. It is preferable that the compound brush  $b_1 b_2$  should be mounted on a brush rocker capable of swivelling round the shaft over a degree divided scale, so that angular distances from some starting-point may be accurately obtained.

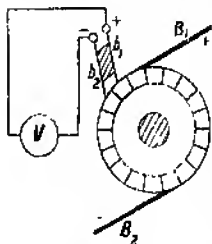


FIG. 75.

The method has the advantage that only a comparatively short range accurate reading voltmeter is needed, say, to about ten volts or so in the case of a 100-volt machine. The main brushes  $B_1B_2$  must be arranged to allow  $b_1b_2$  to pass them on the commutator.

The readings of the voltmeter will be different according to whether the machine is giving no current at all or its full-load current. If the machine is shunt wound it may in the former case be self-exciting, as the shunt current will be so small compared with the load current as to not affect the distribution round the commutator.

If now the readings on  $V$  are plotted on the ordinates of a curve with the corresponding angular positions right round the commutator on the abscissæ, the curve will not only show the variation of E.M.F. of the coil, but will show also the distribution of the magnetic field in the air gaps, the best position for the brushes and the "*angle of Lead*" which must be given to these when running on full load due to the shifting round of the resultant magnetic field  $KK$  (Fig. 73) to  $R_1R_2$ .

### (75) Determination of the Distribution of Potential round the Commutator of a Dynamo. (Mordey's Method.)

**Introduction.**—The following is a convenient and simple method of finding the above-named distribution, and consists in measuring the potential between one of the main brushes and a single movable or *Pilot* brush capable of swivelling right round the commutator. It is then found that the potential increases or decreases from that main brush (according to whether it is the negative or positive one) round each half of the armature to the other brush, and that the variation is *regular* in a well-designed, but *irregular* in a badly-designed machine.

To represent the resulting variation or distribution graphically Prof. S. P. Thompson proposes drawing a circle  $OHC$  (Figs. 76 and 77) to represent the commutator and divide it into, say, 36 equal parts of  $10^\circ$  each, set off radially outwards from the circle,

lines  $\alpha$  potentials at the various angular positions of the pilot brush, thus getting the outer or potential curve  $OAD$ .

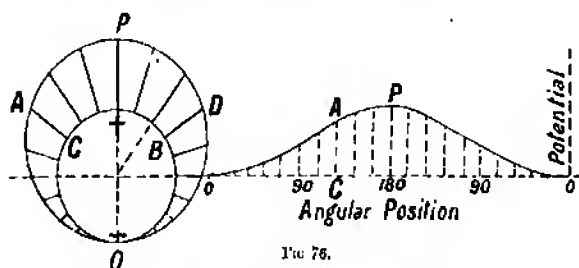


FIG. 76.

Next obtain the developed diagrams to the right of Figs. 76 and 77 by laying off a horizontal base to represent the length of the circumference of the circle  $OBC$ , then at the proper points along this angular line set up the radial lines from the left-hand Figure, due regard being paid to sign.

Fig. 76 is the result obtained with a well-arranged dynamo, and Fig. 77 with a badly-arranged one.

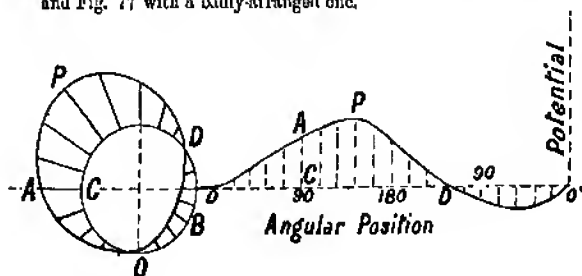


FIG. 77.

These curves show us several points, as, for example, the steepness of the curves in the right-hand diagrams enable an idea of the relative activity or idleness of the coils in these positions to be obtained, also the position of the brushes to give the best result and the distribution of field in the air gaps.

Fig. 77 may result from a machine in which the pole pieces are badly shaped, or the brushes badly placed.

**Apparatus.**—Dynamo to be tested, fitted with a third brush or pilot brush  $P$  capable of swivelling round the whole circle divided into degrees, and of making contact on the commutator at any position; a rather long range accurate reading voltmeter  $V$ , and arrangements for taking a load from the machine when required.

**Observations.**—(1) Calling the two main brushes  $B_1$  and  $B_2$  and the pilot brush  $P$ , connect  $V$  between the negative main brush and  $P$ , the dynamo being shunt wound and excited off its main brushes  $B_1, B_2$ .

(2) Run the machine on *open external circuit* at normal speed, and adjust  $P$  in line with the negative brush, which latter has been previously adjusted to give no sparking.

(3) Note the reading on  $V$  and the degree scale of  $P$ , and repeat every  $10^\circ$  right round the commutator *at constant speed*.

(4) Repeat 2 and 3 for a full-load current taken from  $B_1, B_2$ , adjusting the speed (constant) to give the same voltage as before.

(5) Repeat obs. 1-4 with the same machine run as a motor.

(6) Tabulate your results in a convenient form, and plot a pair of curves for each test in the way indicated above.

**Inferences.**—State very clearly what you can deduce from your curves of distribution, and indicate in the developed diagram the positions of the poles, brushes, and resultant magnetic field of the machine.

## (76) Determination of the Distribution of Potential round the Commutator of a Dynamo. (Mordey-Swinburne's Method.)

This is a neat modification of the preceding method, and consists in connecting a high resistance wire  $V_1V_2$  across the main brushes  $B_1, B_2$ , and finding by means of a sensitive detecting galvanometer  $G$  a position  $C$  along the resistance  $V_1V_2$  such that  $G$  does not deflect. The point  $C$  is then at the same potential as  $P$ ; hence since  $V_1V_2$  is fixed, the distance  $V_1C$  or  $V_2C$  gives the relative potentials for various positions of  $P$ . The potentio-

meter  $V_1CV_2$  can be easily calibrated by taking one single reading of the volts ( $V$ ) across  $B_1B_2$ , whence the distances  $V_1C$ , for

instance, in volts  $= \frac{V_1C}{V_1V_2} \text{ of } V$

where  $V_1C$  and  $V_1V_2$  are in ohms, say, or some known units.

The speed must be constant throughout the test, so as to maintain  $V$  constant. Being a zero method it is very accurate, and has the advantage of not requiring a voltmeter which has to be equally accurate over its whole range, but only at one point.

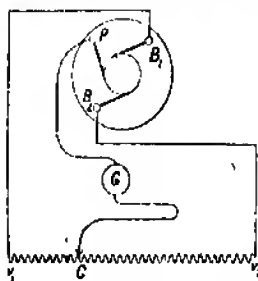


FIG. 78.

### (77) Analysis of the Total Internal Loss of Power in Direct Current Dynamos and Motors.

**Introduction.**—In test No. 82, p. 220, it is pointed out that the total internal loss of power in a direct current dynamo or motor is made up as follows—

(i) *Copper Loss* occurring in the armature and field coils, caused by heating due to the passage of the current.

This is at once easily calculable from the relations there given for finding the copper loss in either series, shunt or compound machines, when the resistances of the several coils, and the respective currents which each carries, is known. The loss in each circuit varies as the square of the current.

(ii) *Mechanical Friction* due to air churning or resistance, brush and bearing friction, each of which varies as the speed simply.

(iii) *Eddy Current* or *Foucault Current* loss occurring in the armature core, and also in the armature conductors, and varying as the square of the speed for the same excitation, since the eddy currents will be directly  $\propto$  speed at constant excitation while the watts used in producing them will vary as the square of these currents, or if  $W_E =$  Watts wasted in eddy currents

and  $n$  = speed in revs. per min., then loss from this cause is  $W_E \propto n^2 K_E$ , where  $K_E$  is a coefficient depending on the eddy loss.

(iv) *Magnetic Hysteresis* in the core due to reversals of magnetization in it as it rotates and  $\propto$  to its speed. If  $W_H$  = the loss from this cause and  $K_H$  its co-efficient, then  $W_H \propto n K_H$ ; hence the total iron loss  $W_I = W_H + W_E = n K_H + n^2 K_E$ .

This equation has been made use of in several methods for separating these losses. Thus in Mr. Mordey's method, which is applicable to determining the losses in an *unwound* armature core as well as a wound one, the armature to be tested is driven, when in position between its own field poles, at different speeds ( $n$ ), with its field (a) unexcited, (b) excited to a constant degree, (c) excited to various degrees, by an electromotor, and the power so required measured by a dynamometer or by knowing the efficiency of the motor accurately.

On plotting a curve between the speed ( $n$ ) and the powers  $W$  required to drive at different speeds in a constant field, the constants  $K_H$  and  $K_E$  can be found from it.

Mr. Kapp's method is a slight modification of the preceding, and is only applicable to a ready-wound armature core. It consists in measuring the power  $W$  required to run the armature to be tested at different speeds in a constant field  $N$ , by running the armature itself as a motor "light," and noting the corresponding voltage  $V$  and current  $A$  taken at each speed ( $n$ ).

If then  $T_a$  = total number of armature turns all round we have the fundamental relation  $V = T_a N n 10^{-8}$ .

But  $W = AV = A T_a N n 10^{-8} = n K_H + n^2 K_E$

$$\therefore A = \frac{K_H}{T_a N 10^{-8}} + n \frac{K_E}{T_a N 10^{-8}} = (\text{a constant} + n \times \text{a factor}).$$

On plotting therefore the curve between  $A$  and  $n$  to the axes  $OX$  and  $OS$  with ( $n$ ) along  $OS$ , we shall obtain the straight line  $PQ$ . The ordinate  $OP$  is  $\propto$  current required to overcome friction and hysteresis, while  $\tan \theta \propto$  the eddy current effect. If  $OP$  is plotted to a scale of current, then  $K_H = OP, N T_a 10^{-8}$ , when  $F = \frac{W - n K_H}{n^2}$  is also known.

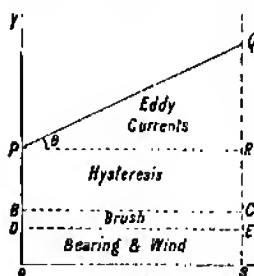
$$\text{We also have } \frac{OP}{QS} = \frac{\text{Hysteresis} + \text{Friction}}{(\text{Hysteresis} + \text{Friction}) + \text{Eddies}}.$$

Thus the three separate factors or losses are each determined.



The following graphical method of separating the various losses is a simple and convenient one, and independent of any mathematical treatment. It is due to Mr. R. H. Housman, and is as follows—

Separately excite the field magnets to the normal amount and keep this constant. Note the current and speed of the armature



when running light as a motor for different noted voltages applied to it. Plotting current, which  $\propto$  torque with given field on the ordinates, and voltages which  $\propto$  speed with given field on the abscissae, or Joules per revolution on the ordinates and revs. per second on abscissae, the straight line PQ (Fig. 79) is obtained cutting the current axis in P.

If Q is any point on PQ and QS is parallel to OP, then the total loss for that speed OS is given by  $QS \times SO$ . If PR is parallel to OS, then the area  $PS \propto OS \propto$  power lost in hysteresis and friction together, and area  $QR \times RP \propto OS^2 \propto$  power lost in eddy currents where  $QP \propto RP \propto OS$ . Repeating the above with a different excitation will give a second line  $P'Q'$ , usually parallel to PQ, showing that the eddy currents are constant for a given voltage.

It may be noticed that the total loss corresponding to any point such as Q on PQ = product of co-ordinates =  $OS \times QS$ , and not the area of the Fig. PQSQ. In other words, the Fig. represents the nature of a dynamo Characteristic rather than the indicator diagram of a steam-engine.

To obtain the total mechanical friction losses, run the armature with brushes down, field disconnected and unexcited by a direct coupled motor, and note the increase of current required to drive over that needed for the motor alone. Plotting this current OB on the ordinates and drawing BC parallel to OS, the area OC  $\propto$  total mechanical frictions, and  $\therefore$  BR must be  $\propto$  to the hysteresis loss alone. On noting this excess driving current with the brushes up, we get OD, and finally the area OE  $\propto$  bearing and wind friction only. DC being  $\propto$  the brush friction alone.

The total losses for a given voltage will be a minimum for a certain induction in the armature core, usually between 15,000 and 16,000 lines per square cm. Since the hysteresis losses increase rapidly with increase of field, while the frictional losses increase with decrease of field due to the higher speed needed to obtain the same voltage.

For high inductions up to 18,000 or 20,000 the eddy currents cause the curve to bend upwards, and also the angle  $\theta$  to be greater. This is probably due to the eddies generated by the stray leakage field through the shaft, etc. If the line  $PQ$  bends, it shows that the eddy-current losses are producing perceptible demagnetization on the field. Since both the eddy and hysteresis losses increase with armature current, these losses should readily be measured with full-load armature current flowing by using the method of Fig. 85, which with careful adjustment of excitation will give considerable range of speed for constant armature current.

This question of the separation of the various losses is of great importance to the dynamo maker, enabling him to see in what way a machine is faulty, i. e. whether the eddy-current loss is excessive due to insufficient lamination, or the hysteresis too great due to too hard or inferior quality of iron. We will now consider a complete experimental analysis in detail.

**Apparatus.**—Exactly the same as that prescribed for test 95, and in addition an auxiliary motor should be available for coupling *direct* to the machine to be tested.

**Observations.**—(1) Carry out observations 1–3, test 95.

(2) Repeat 1 for an excitation 25% above and 50% below the normal.

(3) Disconnect all apparatus from the machine tested, and also the field from the armature. Connect the instruments up with the auxiliary motor, so as to measure the power taken to drive it. Demagnetize the field magnets of the motor to be tested by sending round the field coils a gradually diminishing (to 0) alternating current.

(4) Measure the voltage and current needed to run the auxiliary motor at some ten different recorded speeds between 0 and the maximum allowable.



ence between the watts at any given excitation, and at this zero value, will be the power lost in hysteresis, eddies, and mechanical frictions.

Again, if the curves are plotted between Joules per revolution as ordinates, and revs. per sec. as abscissas, the friction line *BC* separating frictional and electro-magnetic losses has a fixed position in the diagram; whereas, with the axes denoting current and volts, a different friction line has to be drawn for each excitation, thus making it difficult to see what proportion of the whole loss is electrical and what frictional, when more than one set of curves corresponding with different excitation is drawn on the same curve-sheet.

### (78) Measurement of the Coefficient of Magnetic Leakage " $\nu$ ," and of the Relative Distribution of the Waste Field of Dynamos and Motors. (Ballistic Method.)

**Introduction.**—The present test has a most important bearing on the design of the magnetic circuit of a dynamo or motor, for since only a fraction of the total number of lines of magnetic force, generated by the field magnets, are usefully employed in cutting the armature conductors and so generating the requisite E.M.F., the results of the test enable the designer to allow for this discrepancy, providing he knows the coefficient of magnetic leakage " $\nu$ " for the particular form and type of machine in question.

In addition to this, the relative distribution of the waste field around the machine enables defects in the design of the magnetic circuit to be seen and corrected, for at the best the magnetic circuit of a dynamo or motor is very imperfect.

It should be remembered that leakage of magnetic lines of force will take place across any two points between which there is a difference of magnetic potential, the magnitude of which leakage will depend directly on this potential difference, and inversely on the magnetic resistance of the path.

The following is a convenient method of measuring or comparing the relative amounts of leakage in different parts of a dynamo,

and therefore the *static* leakage coefficient  $\nu$  for the machine; the term *static* being here used to denote the value of  $\nu$  obtained when the armature is at rest, for it is well known that an armature delivering current exerts a demagnetizing action on the field which directly promotes leakage. Assuming the normal excitation constant, the leakage will increase with the output, and it will largely depend on the degree of saturation of the iron and on the relative magnetic reluctances of the various parts. The method depends on the measurement of induced currents produced by moving either (1) an exploring coil so as to cut the field to be tested, or (2) the field in such a way as to cut the coil, the latter method being here adopted. Either the relative or absolute numerical values of the stray and useful flux in the various parts can be found, the relative values being obtained with reference to that part in which the flux is a maximum which can be taken as unity. Knowing these, the absolute values can be obtained by running the armature at a known speed and measuring the E.M.F. without allowing it to develop current and thereby distort the field. The useful armature flux can now be at once calculated, and from it, that in each of the various parts, or thus:—suppose we have a circuit consisting of a ballistic galvanometer, resistance box, earth inductor of  $N_1$  turns, mean area  $A_1$  square c.m.s. in series with an exploring coil of  $N_2$  turns, mean area  $A_2$  square c.m.s. wound round the magnetic field to be tested. If now the inductor, with its plane vertical or horizontal, is rotated rapidly through  $180^\circ$ , cutting the earth's field of strength  $F_1$ , then the total quantity of electricity set up in the transient current is  $Q_1 = \frac{2N_1 A_1 F_1}{R_1} = K \sin \frac{1}{2} \theta_1^\circ$  where  $K$  = ballistic constant,  $R_1$  = total circuit resistance,  $\theta_1^\circ$  = angular throw in degrees. If the exploring coil is now made to cut the field to be tested of strength  $F_2$  by suddenly making, breaking, or reversing the exciting current, we get  $Q_2 = \frac{N_2 A_2 F_2}{R_2} = K \sin \frac{1}{2} \theta_2^\circ$  where  $\theta_2$  and  $R_2$  have the same meaning as before.  $\therefore$  Dividing we get  $F_2 = F_1 \frac{2N_1 A_1 R_2}{N_2 A_2 R_1} \times \frac{d_2}{d_1}$  lines per square c.m. in the loop or search coil (in absolute measure) where  $d_1$  and  $d_2$  = scale deflections corresponding to  $\theta_1$  and  $\theta_2$ .

As, however, it is the total field ( $A_1 F_1$ ) which we really desire to obtain, and denoting this by  $F_T$

$$\text{we have } F_T = F_1 \frac{2N_1 A_1 R_2}{N_2 R_1} \times \frac{d_2}{d_1} \text{ lines.}$$

**Apparatus.**—Earth inductor  $E$ ; resistance box  $R$ ; charge and short circuit key  $K$ ; ballistic mirror galvanometer  $G$  (p. 569), having a small log decrement and periodic time about 8 or 10 seconds, so that this may be large compared with the time of flow of  $Q_1$  and  $Q_2$  which can therefore pass through the coil before it begins to move. A shunt wound dynamo to be tested; ammeter  $A$ ; rheostat ( $r$ ) (p. 593); quick break switch  $S$ ; and source of current  $B$ .

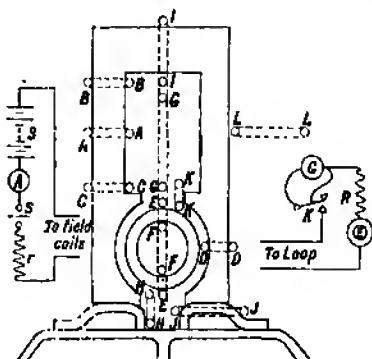


FIG. 80.

**Observations.**—(1) Adjust the needle of  $G$  to zero, and wind a single complete turn of wire on the dynamo at position  $A$ , connecting it up with the other apparatus as indicated in Fig. 80. The F.M. coils must be disconnected and excited separately from  $B$ .

(2) Close  $S$  and adjust ( $r$ ), so as to get normal excitation through the F.M. coils.

(3) Close  $K$ , open  $S$ , and adjust  $R$  by trial so as to get a convenient throw on  $G$ , then note its value ( $D_1$ ) on breaking, and ( $D_2$ ) on making circuit at  $S$ , the excitation being that in 2. Repeat this twice and take the mean of each, calling it ( $d_2$ ).

(4) Repeat 1-3 for each of the positions of the exploring loop indicated by the letters *B, C, D, E, F, G, H, I, J, K, and L*, respectively.

(5) Repeat 4 for excitations 50% higher and 50% lower than the normal, and in each case calculate  $v$  from the formula,

$$v = \frac{\text{Total Field}}{\text{Useful Field}}$$

(6) Let down the brushes and run the machine at a known speed, measuring the E.M.F.  $E$  at each of the three excitations used, and tabulate as follows—

NAME . . .

DATE . . .

$N_f = \dots$  turns  
 $A_f = \dots$  sq. cms.  
 Galv. resistance  $g = \dots$  ohms.  
 Inductor resistance  $r_i = \dots$  ohms.  
 Total resistance  $R_f = \dots$  ohms.

$F_1 = \dots$  C.G.S. units.  
 $d_1 = \dots$  S.W.G. diam.  
 Total No. armature conductors  $C = \dots$   
 speed  $= \dots$  revs. per min.  
 $= \dots$  revs. per sec. ( $n$ ).

Position of loop.	Turns on loop.	Area sq. c. ms.	Box resistance.	Total resistance.	Exact inductance.	Threw on.	Mean throw at each position.	Useful flux in armature.	Flux at each position.	Flux $F_f$	$v$ .
	$N_p$	$A_p$	$R_p$	$R_p$	$L_p$	Brushing $B_1$ Working $B_2$	$\log \frac{1}{2} (d_1 + d_2)$	$\frac{F_1}{N}$	$\frac{F_2}{N}$	$\frac{F_f}{N}$	

**Inferences.**—State clearly all the inferences which can be drawn from the results of the above experiments, and point out their bearing on the design of field magnets for dynamos and motors.

### (79) Magnetic Characteristic of a Dynamo with varying Air Gaps.

**Introduction.**—It is of considerable importance, especially in the design of dynamos, to know the effect which the length of air gap, between the field magnet (F.M.) pole faces and armature core has on the excitation required to force a given number of magnetic lines of force through the core. For convenience the curve showing the relation between the amp.-turns (A.T.) or magneto-motive force (M.M.F.) which  $= \frac{4\pi}{10} \times \text{A.T.}$  in the F.M.s and the total useful flux of lines ( $N$ ) through the armature will be called the *Magnetic Characteristic* for the air gap used. The flux ( $N$ ) can be found in two ways: (1) by using a ballistic galvanometer in series with a "search coil" temporarily wound on the armature and noting the throws produced on the galvanometer by making, breaking, or reversing known currents in the F.M. coils; (2) by running the armature mechanically and noting its E.M.F. speed, and number of conductors round periphery,  $N$  being then calculated from the fundamental formula  $E = NuC \div 10^8$ . This is the best and more practical method to employ, because the armature will now exert a slight demagnetising action on the F.M.s tending to increase leakage and approximate more nearly to actual working conditions. The Exp. is divided into three distinct parts, viz. the determination of the relation between—

(a) The M.M.F. and flux ( $N$ ) through armature with constant air gap.

(b) The air gap and flux ( $N$ ) through armature with constant M.M.F.

(c) The air gap and M.M.F. through armature with constant flux ( $N$ ) in armature.

**Apparatus.**—The dynamo  $D$  capable of being driven mechanically; tachometer  $V$ ; ammeter  $a$ ; switch  $S$ ; rheostat  $r$  (p. 599); supply of electricity.

The machine  $D$  to be tested must be specially constructed in order to be able to operate this test. As shown in Fig. 81, the pole pieces are each capable of being made to approach or recede from the armature by turning a massive screw bolt  $b$  fitted to



each, by means of a suitable key. The distance apart of the pole tips can be read off on a scale  $C$  fixed to the body of the machine.

*Note.*—The pole tips must never be closer together than the two zero scale divisions which will be termed their normal position

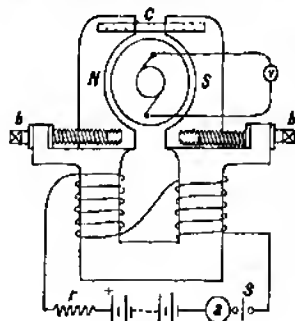


FIG. 81.

in what follows, and must always be left at this distance after the test is over.

To increase this distance turn the screws clockwise.

It will be noticed that the initial slopes of the curves in (a) are determined by the air gap, also that the air gap causes the curve to bend over.

All lubricators must feed properly before the machinery is started.

**Observations.** — a — (1)

Connect up as shown in

Fig. 81, and adjust the pointers of all the instruments to zero.

(2) Set the pole tips at exactly the normal distance apart and adjust the speed so that with the maximum excitation allowable in the F.M. coils 25% above normal, the E.M.F. can be read off on  $v$ .

(3) With air gap and speed constant, adjust the excitation to about  $\frac{1}{4}$  of the maximum allowable. Note this reading  $A$  and that on ( $v$ ) viz.  $E$ .

(4) Repeat 3 for about eight ascending equal increments of current to about 25% above the normal excitation.

(5) Repeat 3 and 4 for the pole tips half-way and the farthest apart.

(6) Repeat 3-5 for the same current values descending.

(7) Plot curves in each case with M.M.F. as abscissae and  $N$  as ordinates.

$\beta$ —(1) Adjust the exciting current to the normal value and the speed so that the E.M.F. can be read off on  $v$ .

(2) With M.M.F. (i. e.  $A$ ) and speed constant and the pole tips at exactly the normal distance apart, note the reading ( $E$ ) on  $v$ .

(3) Repeat 2 for eight different distances increasing by  $\frac{1}{2}$  at a time to the maximum possible.

(4) Repeat 2 and 3 for a return set of distances to the minimum (normal).

(5) Plot curves in each case with distances between iron of armature and pole face as abscissæ and  $N$  as ordinates.

$\gamma$ —(1) Adjust the excitation to  $\frac{1}{2}$  maximum and the speed so that a suitable low reading of, say,  $\frac{1}{4}$  maximum voltage is obtained on  $v$ .

(2) With  $N$  (i. e.  $E$ ) and speed constant and the pole tips at exactly the normal distance apart, note this distance ( $d$ ) and the exciting current  $A$ .

(3) Repeat 2 for eight values of ( $d$ ) rising by  $\frac{1}{2}$  of the maximum at a time to the maximum, noting  $A$ , at each position, which is necessary to keep  $E$  constant.

(4) Repeat 2 and 3 for a return set of distances to the minimum (normal).

(5) Plot curves in each case with M.M.F. as abscissæ and ( $d$ ) as ordinates.

NAME . . .

DATE . . .

No. Armature conductors  $C$  = . . .

External diam. iron core = . . . inches

Total F.M. turns ( $T$ ) = . . .

Internal " " " " " "

Net length " " " " " "

Speed in R.p.m.		Distance between pole tips ( $d$ ).	Distance between iron of core to core.	Exciting Current, $A$ amperes.		E.M.F. on ( $v$ ) $E$ .		M.M.F. = $\frac{4\pi}{10} A.T.$	Flux $\Phi$ in $10^6$ lines.
Per Min.	Per Sec. ( $\omega$ ).			Increasing.	Decreasing.	Increasing.	Decreasing.		

**Deductions.**—State very clearly all the inferences which you can draw from your results and point out their bearing on dynamo design.

## (80) Localization of Faults in Magnetizing Coils. (Induction-Ballistic Method.)

**Introduction.**—When a magnetizing coil of insulated wire is wound on a metallic bobbin, the latter is usually insulated on the inside by a thin strata of insulating material before winding on

the covered wire. Notwithstanding this, it may and does sometimes happen that the wire core becomes "shorted" to the metal-work of the bobbin, through the covering and insulation of the bobbin. This is particularly liable to be the case in shunt coils of dynamos which are wound on metal "formers," insulated with vulcanized fibre tissue before winding.

Such a fault, through poor contact of, in many cases, a very uncertain nature, gives trouble in the ordinary methods of testing for its position, by giving unsteady readings. Thus the ordinary resistance methods are extremely liable to be vitiated by variable contact resistance at the fault. The following method for localizing the position of the fault by means of *induced currents*, measured ballistically, is often a more convenient and reliable one for the purpose.

**Apparatus.**—Metallic bobbin or former  $F$  to be tested, wound with the magnetizing coil ( $m$ ) which is "shorted" to frame at the

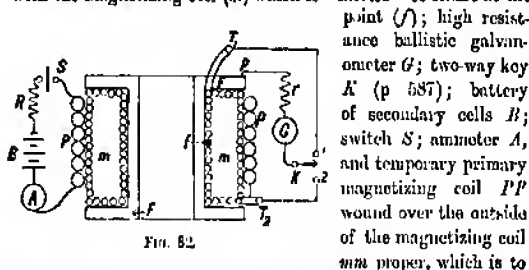


FIG. 82.

point ( $f$ ); high resistance ballistic galvanometer  $G$ ; two-way key  $K$  (p. 587); battery of secondary cells  $B$ ; switch  $S$ ; ammeter  $A$ , and temporary primary magnetizing coil  $PP$  wound over the outside of the magnetizing coil  $mm$  proper, which is to

be tested; rheostat  $R$  (p. 606); known high resistance box  $r$ .

**N.B.**—It will be noticed that, as represented in Fig. 82, the fault ( $f$ ) is on the first layer of turns next to the frame  $F$ , and we will suppose that the turn at ( $f$ ) is making contact there with the metallic frame ( $F$ ). Thus it will be seen that the point ( $f$ ) divides the total number of turns on the whole bobbin into two parts between the leading out wires  $T_1 T_2$  of the coil, so that total turns = turns between  $T_1$  and  $f$  + turns between  $T_2$  and  $f$ .

**Observations.**—(1) Connect up as in Fig. 82, and adjust  $A$  and  $G$  to zero, the temporary coil  $PP$  having been previously wound on and a wire soldered to any point ( $p$ ) on the metallic bobbin frame  $F$ .

(2) With  $R$  full in, close  $S$  and adjust the current on  $A$  to some convenient amount. Next also close  $K$  to stud 1 and adjust  $\tau$  to such a value as will give, say,  $\frac{1}{2}$  or  $\frac{3}{4}$  scale deflection  $d_1$  on  $G$  when  $S$  is opened suddenly. Repeat two or three times with the same constant current, both made and broken in  $P$ .

(3) Close  $K$  to stud 2 and repeat 2 above with the same current, noting the new resistance out in  $\tau$  to give a suitable first throw on  $G$ .

(4) Repeat 2 or 3 for about four or five current strengths  $A$  so as to obtain finally different throws on  $G$  which will check one another, and calculate the position of the fault ( $f$ ), or the number of turns to be unwound, to reach it, from the relation

$$\frac{N_1}{N_2} = \frac{\text{turns between } T_1 \text{ and } f}{\text{turns between } T_2 \text{ and } f} = \frac{\text{mean 1st throw } d_1}{\text{mean 1st throw } d_2} \times \frac{r_1}{r_2} \text{ approx.}$$

where  $r_1, r_2$  are the total resistances of  $r + G$  when obtaining  $d_1$  and  $d_2$  respectively, and which are assumed to be very large compared with the contact resistance at  $f$  and also the resistance of the turns between  $f$  and both  $T_1$  and  $T_2$ . If the resistance of the coil ( $w$ ) is from 5 to 20 ohms then  $(r + G)$  should if possible be at least 10,000 ohms.

NAME . . . . . DATE . . . . .  
Coil tested: Total Turns  $N = \dots$  Total Resistance  $R_0 = \dots$   
Galvanometer Resistance  $G = \dots$  Ohms at . . . ° C.

Current for reference only.	1st throws on $G$ .		Box resistance.		Current Resist.		Ratio $N_1/N_2$	Turns to unwind $N_2$
	mean $d_1$ .	mean $d_2$ .	$r$	$r'$	$r + G$ $= (r_1)$ .	$r' + G$ $= (r_2)$ .		

N.B.—It will be noticed from the formula in 4 that if  $\tau$  is adjusted so that  $d_1 = d_2$ , then

$$N_1/N_2 = \frac{r_1}{r_2} \text{ or } N_2 = \frac{r_2}{r_1} \cdot N_1$$

or again if  $r$  is kept constant throughout,

$$\text{then } N_1/N_2 = d_1/d_2 \text{ or } N_2 = \frac{d_1}{d_2} N_1$$

If  $G$  is insensitive an iron core may be inserted in the coil to form a closed circuit if possible; this will increase the flux for a given current made or broken in  $PT$ , and therefore also the first throws  $d_1, d_2$  on  $G$ .

This has the further advantage that  $N_1$  and  $N_2$  will now enclose the same number of lines of force, which is only approximately true if there is no iron core and the coil long.

It should be observed in passing that even a simpler method still than the one described above, for finding the position of the fault ( $f$ ), would be to employ a slide wire or meter bridge or other convenient form of potential divider in the following manner. Connect the ends  $T_1$   $T_2$ , Fig. 82, of the faulty field coil to the extremities of a meter bridge wire and also to two or three Leclanché cells; connect the galvanometer  $G$ , which need not now be ballistic, but which must be sensitive, between the metallic former at  $p$  and the slider key of the bridge wire. Now move the key such that on tapping it  $G$  does not deflect. Then the lengths  $T_1f$  and  $fT_2$  of the faulty coil are in the proportion of the corresponding lengths of the stretched wire either side of the  $K$ , and are therefore known if the gauge of winding and its resistance (which can be measured in the ordinary way) are known.

### (81) Determination of the Rise of Temperature and Increase in Resistance of Magnet-windings.

**Introduction.**—Since every magnet coil has some resistance, which is usually considerable in shunt or pressure coils but small in series or current coils, it follows from Joule's law that heat must be generated in them when excited. The amount of heat developed per second by a current of ( $I$ ) amperes flowing through, or a pressure of ( $V$ ) volts across the terminals of, a coil

of  $R$  ohms resistance is  $\propto I^2R$  or  $\frac{V^2}{R}$ . Any coil must therefore

have such an external surface for radiation of heat relatively to the amount of heat developed in it, that the "steady" temperature attained when the rates of production and dissipation of heat become equal is not high enough to deteriorate the insulation of the winding. The maximum limit to this "steady" final temperature is usually fixed at about  $50^\circ\text{C}$ ., for it is found that the commoner insulating materials used generally begin to deteriorate with temperatures exceeding 60 to  $70^\circ\text{C}$ .

Admiralty specifications, however, prescribe that after a six-hours' run at full load, no accessible part of a machine may show a temperature of more than  $70^{\circ}\text{F}$  ( $= 38^{\circ}\cdot 8\text{C}$ ) above the surrounding air. This would seem unnecessarily low, but from remarks to follow may not actually be so.

In the case of dynamos and motors the rise of temperature and its final steady value is required for the armature, series or shunt coils, commutator, bearings and frame. Further, it has been shown that the radiating facility of a surface in contact with iron is nearly twice as good as when it is exposed to air.

Except in special measurements and research, when perhaps thermo-couples and their equivalents may be used, the temperature rise of coils while energized is always obtained either (1) by thermometer, the bulb of which is placed on the coil and covered with a pad of cotton wool, or (2) by resistance measurement, obtained from the readings of an ammeter in series with, or a voltmeter across, the coil and the application of Ohm's law. This latter method is the one usually employed in a test room, is the most accurate of the two, and the quickest method of finding the "true mean rise" of temperature, especially with series coils. With shunt coils this resistance method can be effected by switching the supply off and then quickly measuring the resistance of the coil by the Wheatstone Bridge method. Usually the true mean rise of temperature by resistance tests is found to be at least 1·4 to 1·6 times greater than the apparent mean rise by thermometer due to the temperature of the layers of winding increasing from the outer one to that situated about three-fourths of the thickness of coil from it, and then decreasing again to the inner layer next to the iron core.

If  $R_c$  = the resistance of the coil cold, and  $R_h$  that when hot,

then  $R_h = R_c(1 + \alpha(t_h - t_c))$  approximately,

or  $\frac{R_h}{R_c} = \frac{1 + \alpha t_h}{1 + \alpha t_c}$  more accurately,

where  $t_c$  and  $t_h$  = the temperature in deg. cent. of the coil, cold and hot respectively, and  $\alpha$  = the temperature coefficient of the material which for copper = 0·00428 ohm per ohm per  $1^{\circ}\text{C}$ .

$$= \frac{1}{23} \times 0\cdot00428 = 0\cdot00238 \text{ per } ^{\circ}\text{F}.$$

$$\therefore \text{the rise of temp.} = (t_h - t_c) = \frac{R_h - R_c}{a R_c}$$

$$= 2.73 \frac{R_h - R_c}{R_c} \text{ deg. cent.} = 420 \frac{R_h - R_c}{R_c} \text{ deg. Fahr.}$$

If now  $T$  = final temp. rise above surrounding air,

$S$  = total heat radiating surface in  $\text{ft}^2$  (exclusive of end flanges and internal surface, if any),

$W$  = total watts wasted in the coil at full load  
= total  $I^2 R$ ,

$$\text{then } T \propto W \propto \frac{1}{S} \quad \text{or} \quad T = \frac{W}{S} \times K,$$

where  $(K)$  = a heating constant depending on the depth of winding, amount of fanning by the armature, and whether the surrounding air is still or circulating, and may be taken as 75 for the usual shape and size of field coils of dynamos and motors, especially of multipolar types, excepting when iron clad.

$$\text{Hence} \quad T = 75 \frac{W}{S} \text{ deg. cent.}$$

and since for shunt bobbins  $W = VI_{sh} = I_{sh}^2 R_{sh}$ .

$\therefore$  for a prescribed temp. rise ( $T$ ) we have

$$\text{max. shunt current } I_{sh} = \sqrt{\frac{T S}{75 R_{sh}}} \text{ amperes.}$$

**Apparatus.**—Magnet coil  $F$  (of, say, a dynamo) to be tested; ammeter ( $a$ ) and voltmeter ( $v$ ) each capable of dealing with the full-rated current and voltage for the coil; switch  $S_1$ ; watch; small bulb thermometer and cotton wool; adjustable high resistance  $r$  for shunt coils, or low resistance for series coils;



FIG. 83.

ammeter  $A$ , voltmeter  $V$ , switch  $S$ , and adjustable load resistance for the main circuit to the armature  $M$ . Separate means for driving  $M$ .

**Observations.**—(1) [*Armature  $M$  stationary*]. Connect up as shown on the left half of Fig. 83 and adjust  $a$  and  $v$  to zero, if necessary. Note the temperature of the air of the room by the

thermometer, secure the thermometer with its bulb *touching* the outside of the coil, and cover the bulb with a pad of cotton wool.

(2) With  $r$  full in, close  $S_1$  and quickly adjust  $r$  so that  $v$  or  $a$  shows the normal value for the coil, and note the readings of both  $v$  and  $a$ , the thermometer and the time.

(3) By adjusting  $r$  maintain ( $a$ ) constant in testing a series coil, or ( $v$ ) constant in testing a pressure coil, either at the above normal value, and note the readings of  $v$ ,  $a$ , the thermometer and time, say every 10 minutes for the first  $1\frac{1}{2}$  hours, and then every 15 or 20 minutes, up to the condition when the variable quantity *becomes constant*. Then, again, take the temperature of the room and tabulate as follows—

Name . . . . . Date . . . . .  
 Coil Tested:—Type . . . Thickness . . . External Surface S . . . ☐  
 Temp. of Room at Start . . . "U" at End of test . . . "C."

Time of Reading	Minutes from start	Amperes (a)	Volts (v)	Watts (W = a v)	Resistance of Coil $R_h = \frac{v}{a}$	Calculated Temp. Rise $R_h - R_c$ $t = 233 \frac{R_h - R_c}{R_c}$	Thermometer Reading t.	Whether Motor at Rest or how Running.

(4) [*Armature M driven at Full Load and at Normal Speed*].—Repeat obs. 1-3 after the machine has cooled down to the temperature of the air.

(5) Plot curves to the same axes having time in "*minutes from start*" as abscissae with values of  $R_h$ ,  $T$ , and  $t$  as ordinates; calculate the "heating constant" ( $K$ ) from the relation  $K = \frac{TS}{W}$ , and the maximum value of shunt current suitable for coil tested for the value of ( $K$ ) found, and for a final temperature rise  $T$  of 50° C. above air.

**Inferences.**—Clearly state all that can be deduced from the results of the test, and point out their bearing on temperature testing.

## (82) Efficiency of Direct Current Dynamos. (Swinburne's Electrical Method.)

**Introduction.**—This method, due to Mr. James Swinburne, has the advantage, firstly, in point of accuracy, of being solely an electrical one, and therefore far more accurate than a dynamo-



meter method in which the power required to drive is measured mechanically; secondly, of not requiring another similar machine for coupling to it, in addition to the one tested. The method, which is often termed the "Stray Power" method, is consequently very suitable for employment in workshop determinations, where usually no good transmission dynamometer is available for measuring the H.P. used in driving the generator under test, and is invariably used when Hopkinson's method cannot be applied as, e.g., when no second similar machine is available. The principle of the present and all similar methods is based on the following, namely, that the total power put in = total power given out + total power lost internally or in symbols

$$W_I = W_O + W_L$$

where the suffixes  $I$ ,  $O$  and  $L$  denote the input, output, and total losses in Watts ( $W$ ) respectively.

Thus the commercial efficiency ( $\eta$ ) of the dynamo is at once obtainable from the relation—

$$\eta = \frac{W_O}{W_I} = \frac{W_O}{W_O + W_L}$$

The output in Watts  $W_O$  developed by the dynamo is at once deducible from the product of the volts  $V$  and amperes  $O$  given out. The total loss  $W_L$  in Watts occurring internally in any dynamo is made up as follows—

(a) Copper losses  $L_c$  in armature and exciting coils due to heating by the passage of current, and which can easily be calculated when the currents and resistances are known.

(b) Friction losses  $L_f$  due to air churning, journal and brush frictions.

(c) Magnetic frictions or iron losses  $L_m$  due to Eddy or Foucault currents and magnetic hysteresis. Hence the total internal loss  $W_L = L_c + L_f + L_m$ , and to the quantity  $(L_c + L_m)$  Mr. Swinburne has given the somewhat appropriate name of "Stray Power."

The copper losses are calculable as follows—

Let  $C$  = the current given by the dynamo at its normal voltage  $V$  to some external circuit, and let  $R_a$ ,  $R_{sc}$ ,  $R_{sk}$  be the resistances of the armature series coils and shunt coils respectively of any dynamo to be tested, of which  $R_{sk}$  can be measured by a Wheatstone Bridge and  $R_a$ ,  $R_{sc}$  by the "Potential Difference" method (p. 84). We shall then have for a

Series dynamo  $L_s = C^2 (R_a + R_{sa})$

Shunt dynamo  $L_s = \frac{V^2}{R_{sa}} + \left( C + \frac{V}{R_{sa}} \right)^2 R_a$

Compound dynamo (long shunt)

$$L_s = \frac{V^2}{R_{sa}} + \left( C + \frac{V}{R_{sa}} \right)^2 (R_a + R_k)$$

Compound dynamo (short shunt)

$$L_s = C^2 R_{sa} + \frac{(V - CR_{sa})^2}{R_{sa}} + \left( C + \frac{(V - CR_{sa})}{R_{sa}} \right)^2 R_a$$

The remaining losses, i.e. the stray power ( $L_F + L_m$ ), can readily be obtained by running the dynamo as a motor, the field magnets being separately excited so that the armature has the same magnetic induction as at full load, the E.M.F. supplied to it being at least equal to the total E.M.F. which the machine would develop when running on full load as a dynamo at normal speed. Thus the machine is running on no load other than its own friction, eddy currents, and hysteresis. If  $A$  = current flowing through the armature and  $V_a$  = the voltage across its terminals when the speed is up to normal, then we have

$$\text{Stray power} = (L_F + L_m) = AV_a - I_a$$

where  $L_a$  = copper loss in the armature for the current  $A$  in it.

**Note.**—Only a comparatively small current ( $A$ ) at the proper E.M.F. mentioned above will be required to be furnished by the auxiliary source of current, and if  $R_a$  is very small,  $L_a$  can be neglected in comparison with  $AV_a$  in this last formula.

**Apparatus.**—Dynamo  $M$  to be tested, which for the purposes of discussion merely we will assume is shunt wound; voltmeter  $V$ ; low reading long scale ammeter  $A$ ; rheostats  $R$  (p. 606) and  $r$  (p. 599); tachometer; complete Wheatstone Bridge set (W.B.); two-way voltmeter key  $K$  (p. 587); switch  $S_2$ ; source of current  $E$  at a sufficiently high E.M.F.

**Observations.**—(1) Connect up as in Fig. 84, and adjust the instruments  $V$  and  $A$  to zero if necessary. Switch on  $E$ , when the field should be then

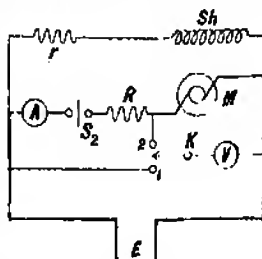


FIG. 84.



**Note.**—There will be only one value, that corresponding to normal speed, in each of the columns 1, 2, 5, 6, and 7 (counting from left to right) in the last table, but as many values in the remaining columns as there are values of amps. *C* assumed between 0 and full load.

(6) Plot the following curves having—

(a) Efficiency as ordinates and Watts developed as abscisse.

(b) Stray power as ordinates and speed of armature as abscisse.

(c) Watts developed as ordinates and Watts to drive as abscisse.

**Inferences.**—State clearly all that can be inferred from your experimental results.

### (83) Efficiency of Direct Current Generators. (Hopkinson's Electrical Method.)

**Introduction.**—The earlier methods of measuring the efficiency of direct current generators, in which the electrical output of the machine was obtained by the product of the ammeter and voltmeter readings, while the total mechanical input was obtained by means of some suitable form of transmission dynamometer, are more or less limited in their application from the fact that a reliable dynamometer is not always available. Even when it is, the method gives only an approximate result, for the error made in measuring the efficiency is proportional to the error made in measuring the input as given by the transmission dynamometer, and which is only too easy to make in an appliance such as this. It will therefore be evident that, given accurately calibrated instruments, any method of measuring the efficiency solely electrically will be capable of giving far more accurate results than could be obtained with any dynamometer.

The present method has this advantage, of being solely an electrical one, and requires two machines of as nearly the same output as possible, the accuracy of the test practically depending on how nearly alike in this respect the two machines are.

They must be capable of being placed in alignment with their shafts coupled mechanically together. The test can be made with either series, shunt, or compound machines, but the shunt is much the simplest.

**Apparatus.**—Accurate ammeters  $A$  and  $a_1$ ,  $a_2$ ; voltmeter  $V$ ; rheostats  $R_1$ ,  $R_2$  for the field circuits (p. 599); change over voltmeter key  $K$  (Fig. 254); dynamo ( $\alpha$ ) to be tested coupled both mechanically and electrically to a similar machine ( $\beta$ ) which runs as a motor. An auxiliary source of current ( $\gamma$ ), such as a storage battery, or another dynamo giving an E.M.F. about equal to the normal of  $\alpha$  and  $\beta$ , and able to supply the losses occurring in the machines  $\alpha$  and  $\beta$ ; switch

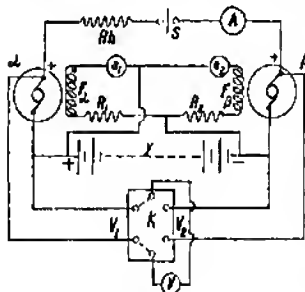


FIG. 85.

$S$ ; rheostat  $RA$  (p. 606, Fig. 274).

**Observations.**—(1) Connect up as in Fig. 85, and make sure that the E.M.F. of  $\gamma$  assists that of the dynamo  $\alpha$  in driving the motor  $\beta$  in the right direction for self-exciting  $\alpha$ .

(2) The respective fields  $F_\alpha$  and  $F_\beta$ , in series with rheostats  $R_1$  and  $R_2$  respectively, are excited from the terminals of  $\gamma$ , as shown, to the normal amount roughly, except that of  $\beta$ , which is weakened to enable it to run as a motor.

(3) With  $RA$  full in to start with, close  $S$  and adjust the auxiliary source of E.M.F. ( $\gamma$ ) and the rheostat ( $RA$ ) so that the machines get up speed, and if possible obtain the normal full load current of  $\alpha$  through the circuit.

(4) Slightly re-adjust  $R_1$  and  $R_2$  to bring  $\alpha\beta$  up to normal speed, then in quick succession measure the volts  $V_1$  at the terminals of the dynamo  $\alpha$  and the volts  $V_2$  at the motor by means of the key  $K$ , at the same time noting the main current on  $A$  and the exciting currents  $a_1$  and  $a_2$ .

(5) If possible obtain three or four different load currents through  $\alpha\beta$  from the normal downwards, and calculate the efficiency  $\Sigma$  from the relation

$$\Sigma = \sqrt{\frac{V_1}{V_2}} \text{ approximately,}$$

and tabulate in a convenient manner.

**Inferences.**—Show how the above relation can be obtained, and state any assumptions made in obtaining it. What corrections would have to be applied to make it rigorously true? Obtain the true value of the efficiency  $\Sigma$  by applying the correction in question.

The test, though simple, requires a certain amount of experimental skill, especially in the case of series and compound machines. Moreover, the starting is somewhat troublesome.

By a slight modification in the connections, the test is a little easier to carry out, and this is shown in Fig. 86. Like the preceding arrangement it involves the use of an auxiliary generator or

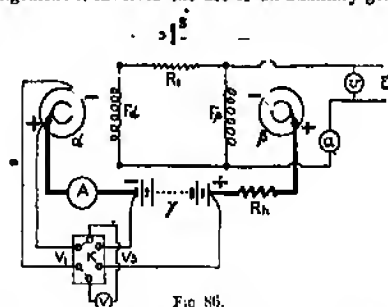


FIG. 86.

set of secondary cells having the same current capacity as the machines under test, and a voltage of from 8 to 25% of that of the generator, according to their efficiencies. This, being, as before, in series with the generator and motor, takes the form of an added voltage to the system.

It is much better to excite the shunts from an independent supply instead of the auxiliary source.

In this arrangement the motor  $\beta$  must have the stronger field, and in order to start, the field  $F_a$  of the generator  $a$  must either be broken or be made comparatively weak by means of the rheostat  $R_1$ .

**Apparatus.**—Similar to that for the preceding test; source of E.M.F. ( $E$ ) necessary to fully excite the shunts  $F_a$  and  $F_\beta$ , the Auxiliary Source  $\gamma$  being as above mentioned.

**Observations.**—(1) Connect up as shown in Fig. 86, and adjust the ammeters  $A$  and  $a$ , and voltmeter  $V$  to zero, etc.

(2) With  $R_1$  and  $Rk$  full in and the voltage ( $v$ ) of the source  $E$  at the requisite value, close  $S$ , adjusting  $Rk$  to obtain full load current  $A$  through  $\alpha$  and  $\beta$ , then simultaneously take the readings of  $\alpha$ ,  $v$ ,  $A$  and the volts  $V_1$  and  $V_2$  across  $\alpha$  and  $\gamma$  by means of the key  $K$ .

(3) Calculate the efficiency of either machine from the relation—

$$\eta = \sqrt{\frac{A \cdot V_1}{A (V_1 + V_2) + \alpha \cdot v}}$$

and tabulate your results in a convenient manner.

#### (84) Measurement of the "Nett" or "Commercial" Efficiency of Direct Current Dynamos. (Kapp's Electrical Method.)

**Introduction.**—The following, being an electrical method entirely, has the advantage that all the measurements are electrical, thereby enabling the efficiency to be determined with far greater accuracy than would be possible with any mechanical transmission dynamometer.

The method consists in coupling the generator to be tested both mechanically (with their armatures in alignment) and electrically to a similar type machine of as nearly equal power as possible, and which latter is made to run as a motor, driving the other, by the weakening of its field, with a rheostat. A small auxiliary generator, giving the normal voltage of the machine to be tested, is required, and must be so connected that it can be placed in quick succession across the terminals of the two coupled machines. The auxiliary source therefore supplies the necessary exciting currents together with the difference of the currents flowing in the two coupled machines. The test, though simple, requires a certain amount of experimental skill, especially in the case of series and compound machines.

**Apparatus.**—Dynamo ( $\alpha$ ) to be tested, assumed to be a shunt wound machine and having its field coil  $F_\alpha$  across its terminals; another similar machine  $\beta$  to act as a motor and having a rheostat  $R_\beta$  in its field  $F_\beta$ ; "change over" switch  $C$  (Fig. 253);

main rheostat  $R_1$  (p. 606); ammeter  $A$ ; voltmeter  $V$ ; switch  $S_1$  and auxiliary source of E.M.F. ( $\gamma$ ), which may consist of the town mains (if the supply is continuous current), secondary battery, or small dynamo giving the normal E.M.F. of the generator  $\alpha$  to be tested.

**Observations.**—(1) Connect up as shown in Fig. 87, and adjust the pointers of  $A$  and  $V$  to zero, if necessary. Arrange the machines  $\alpha$  and  $\beta$  in alignment and couple their shafts together by a suitable coupling.

(2) Turn the "change-over" switch  $C$  to  $\alpha$ , and with  $R_1$  large close  $S_1$  and gradually adjust  $R_1$  and consequently the current until the machines start. Then when they are running at a constant speed, with  $V$  reading the normal voltage of  $\alpha$ , note the ammeter reading  $A_\alpha$ .

(3) Quickly "change over"  $C$  so as to place the auxiliary source  $\gamma$  across  $\beta$  and note the ammeter reading  $A_\beta$  for the same voltage  $V$  as before.

(4) Repeat 2 and 3 for some four or five different speeds, current, and voltages, and calculate the efficiency from the relation—

$$\text{Combined efficiency of the two machines} = \frac{A_\alpha}{A_\beta}$$

$$\text{Commercial efficiency of either machine} = \sqrt{\frac{A_\alpha}{A_\beta}}$$

Tabulate your results as follows—

NAME . . . . . DATE . . . . .  
 Generator tested: No. . . . . Type . . . . . Make . . . . . Normal Volta . . . . . Amps . . . . . Speed . . . . .  
 Machine Coupled: No. . . . . " . . . . . " . . . . . Normal " . . . . . " . . . . . " . . . . .

Speed in Revs. per min.	Voltage $V$ .	Currents in Amps.		Efficiency of	
		$A_\alpha$	$A_\beta$	Combination $\frac{A_\alpha}{A_\beta}$	Generator tested or the other $100 \sqrt{\frac{A_\alpha}{A_\beta}}$ %



**Inferences.**—Show how the expression for the efficiency can be obtained, and dilate on the advantages and disadvantages of the method.

The preceding method can be slightly simplified by the following modifications. As in the above test, the following one involves the use of an auxiliary generator or set of secondary cells, having the same voltage as the machines under test and a current output of about 8 to 25% of that in the armature of  $\alpha$  or  $\beta$ . Being in parallel with the machines to be tested, it takes the form of an added current to the system at the same voltage as the combination under test. The present tests are more convenient, generally speaking, and much simpler as regards starting than those of No. 83. Fig. 88 shows the connections, and the apparatus required is much the same as in the preceding method, except that the change-over switch  $C$ , Fig. 87, is dispensed with.

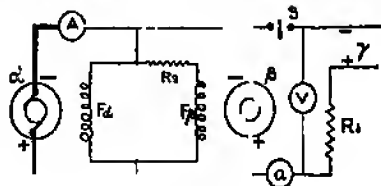


FIG. 88.

The fields  $F_a$  and  $F_b$  can be connected as shown in Fig. 88 instead of as in Fig. 87 if preferred, and it will then be noticed that 87 and 88 are electrically the same when the change-over switch  $C$  is kept as shown, and an ammeter ( $a$ ) inserted in one of the leads connected to it. The source of supply  $\gamma$ , whether power mains or a third generator, must have a voltage at least equal to that of either  $\alpha$  or  $\beta$ . Further, the losses in  $\alpha$  and  $\beta$  are measured directly, and are small compared with the output of  $\alpha$  and  $\beta$ ; hence a small percentage error made in measuring them will be very small compared with the output of  $\alpha$  and  $\beta$ , and will have but little effect on the resulting efficiencies. When two machines of the same size and type have to be tested, this method is almost always used in works for determining their efficiency and heating on a full-load time test.

**Observations.**—(1) Connect up as in Fig. 88 and set all the instruments to zero.

(2) To start up, put  $R_1$  full in and cut out  $R_2$  to short circuit, so that the fields  $F_1$  and  $F_2$  are as nearly as possible of equal and maximum strength. Then close  $S$  and slowly cut out  $R_1$ , when the machines will start up as two similar motors in parallel on no load. The ammeter  $A$  will now read about half that of (a) because  $\alpha$  will be taking about half the supply current.

(3) Now weaken the field  $F_2$  of the machine  $\beta$  by slowly increasing  $R_2$ , which will cause it to run faster and act as a motor, driving  $\alpha$  as a generator. The reading of  $A$  will simultaneously fall, while that of (a) will remain nearly constant; and when  $A$  becomes zero, the voltage of  $\alpha$  will have reached a value just balancing that of the supply  $V$ , and (a) will indicate the current required to run  $\alpha$  and  $\beta$  together at 0 load.

On still further increasing  $R_2$  the current through  $A$  will be reversed, indicating that  $\alpha$  is now commencing to supply, instead of receive, current.

**Note.**—For this reason  $A$  should be either of the moving soft iron needle type of instrument, or of the moving coil permanent magnet type connected in circuit through a reversing switch, otherwise a central zero moving coil type must be used.

(4) Take a series of load currents, as indicated on  $A$ , differing by about equal amounts between 0 and the full-load value for either machine by still further increasing  $R_2$ —noting the readings of all the instruments and the speed at each load,  $V$  being constant at about normal voltage.

**Note.**—This circulating current  $A$  between the machines  $\alpha$  and  $\beta$  will increase with the difference between their field strengths; and the limit is reached when the combination of a large current in the motor armature, and its weak field and high speed, causes excessive sparking.

Tabulate your results as follows—



applied to the pulley to turn it + the power used in exciting. The mean or true power developed is easily obtained if a non-inductive resistance, such as a bank of glow lamps or water rheostat, is at hand which will carry the full load current of the machine, for then the true power = amperes  $\times$  volts. This will not be true if the resistance is inductive owing to the "phase difference" between the current and voltage. For such a case the true power may be obtained by a non-inductive Wattmeter or the 3-voltmeter method (p. 379), etc. The power applied at the alternator pulley to drive it is very commonly obtained by indicating the engine, especially in large "sets." In the present case a transmission dynamometer is used to measure this power. It is of the spring type, and the means for recording the readings of it were devised by Prof. W. Stroud. The indications,

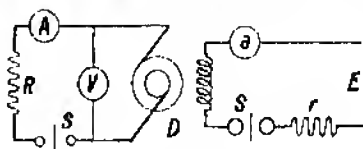


FIG. 89.

which are recorded electrically, represent the nett pull, or difference of tensions in the two sides of the belt in lbs. Then knowing the speed of the alternator and the diameter of its pulley, the H.P. can at once be deduced. For a full and detailed description of the dynamometer, see Appendix, p. 625.

**Apparatus.**—Alternator *D* to be tested; transmission dynamometer complete with its indicating galvanometer *G* (p. 625); tachometer, *a-c* ammeter (*A*) and voltmeter (*V*); *D-C* ammeter (*a*); switch *S*; and non-inductive resistance or bank of lamps *E* (p. 598); exciting circuit containing ammeter (*a*), rheostat *r* (p. 598), switch *S*<sub>1</sub> and exciting E.M.F. *E*.

**Observations.**—(1) Connect up as shown in Fig. 89, and see that all lubricators in use feed slowly. Adjust the secondary E.M.F. (p. 629) for use with the dynamometer, so that when placed directly across the terminals of *G*, a full scale deflection is produced. Then insert it in its proper place.



to which it has been applied, for the electrical driving of workshops, haulage, electric traction, etc., etc., have assumed such proportions as to make the different forms and types of electro-motor at the present day multitudinous. The systematic testing, therefore, of such machines becomes of considerable importance, in order that a comparison may be obtained and a judgment formed of the weak points of any particular type, together with its performance and qualities (whether good or bad) which it possesses.

No motor, least of all one intended for electric tram and railway work, should leave the makers' works or be installed in its proposed occupation without being first thoroughly tested for the following points—(a) *Resistance*, or conductivity of its electrical circuits; (b) *Insulation* resistance between earth or framework of the machine and the copper circuits both individually and collectively; (c) *Brake horse power*; (d) *Efficiency*; (e) *Heating*, or rise of temperature of the various parts of the machine after a run at full load for a specified time. These tests we may now consider more in detail.

(a) **COPPER RESISTANCE.**—That of each of the copper circuits should be separately measured, by the Wheatstone Bridge in the ordinary way (p. 81) in the case of the shunt coils or other circuit of several ohms, and by the Potential Difference Method (p. 84) or voltmeter and ammeter method (p. 86) in the case of the armature and series coils or other low resistance.

(b) **INSULATION RESISTANCE.**—That of the various parts can be obtained by Tests Nos. 43 and 49 (pp. 113, 129) or other convenient method, at a pressure of something like three or four times the normal working pressure of the machine. The insulation resistance of the machine as a whole, when tested at the normal voltage, should not be less than 2000 ohms per volt, whence, of course, that of the individual coils or circuits will be much higher. Some makers merely test the separate parts under a pressure of 2500 to 5000 volts alternating, and if they stand this they are passed as satisfactory. This pressure can conveniently be obtained by means of a small testing transformer, stepping up from, say, 100 to 5000 volts, carefully set fuses being placed in circuit to prevent damage should the insulation break down.

(c) **BRAKE HORSE POWER.**—This may be measured in one of

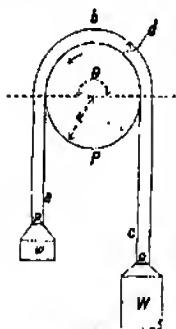


FIG. 90

three ways, depending on the facilities at hand for testing; namely, by an absorption dynamometer, in other words, a modified form of Prony brake, by the "balance" or "cradle" method, or lastly by the electrical method. The last two methods will be described in conjunction with their application to tests which follow later on, but we will now consider the principle involved in the first-named method, reserving the description of some convenient forms of brakes until later. It will be sufficient if we consider the principle of the simplest form of brake, consisting of a rope or band *abc*, of diameter or thickness (*d*), lapped with any arc of contact  $\theta$  (in circular measure), from a fraction of a turn to more than one turn, over the face of the motor pulley *P*, having a radius (*r*) and which rotates we will suppose counter-clockwise, as indicated in Fig. 90. To one end *c* is attached a large weight *W*, and to the other (*a*) a small one *w*. Now when the pulley *P* is at rest, *W* = tension on the right-hand or "tight" side of the rope, while *w* = the tension on the left-hand or "slacker" part of the rope. Then, as *P* rotates, the couple or torque *T*, due to the force of friction between the rope and surface of the pulley, tending to resist motion, and against which the motor does work, is—

$$T' = (W - w) \left( r + \frac{1}{2}d \right) \text{ pound feet,}$$

where (*W* and *w*) are in lbs. and (*r* and *d*) in feet, (*W* - *w*) being the difference in tensions or nett load on the brake in lbs., and  $(r + \frac{1}{2}d)$  the mean effective radius in feet (of pulley and rope together) at which the nett load acts. If (*n*) = number of revolutions per minute made by *P*, then  $2\pi n \div 60 = \omega$ , the angular velocity of the pulley, and the work per second, or the rate at which work is done by the motor on the pulley =  $\omega T'$ . Hence we have—

$$\text{H.P. developed} = (W - w) \left( r + \frac{1}{2}d \right) 2\pi n \div 33,000,$$

where 1 H.P. is equivalent to 33,000 foot-lbs. per minute.

All the power thus measured and appearing at the pulley is

wasted in heating this latter, and herein lies one of the chief difficulties in testing larger H.P.s, namely, the getting rid of the heat so generated by friction, for not only is the heat liable to burn the rope in two if the power of the motor is sufficient, but it also affects the co-efficient of friction ( $\mu$ ) between the rubbing surfaces, thereby causing the brake to jerk and preventing any steady readings being taken.

To obviate this trouble, either the pulley must be water-cooled (see p. 633), or readings must be taken immediately after adding a weight, and then the weight released from the rope. The trouble is further intensified by the motor running at such fast speeds, which is common to this type of driving power. By a slight modification of this form of brake, viz. substituting a spring balance for ( $w$ ), the brake becomes automatically self-regulating for variations of  $\mu$ , for then if  $\mu$  suddenly increases,  $W$  rises, and ( $w$ ), which now is the spring-balance reading, decreases, therefore  $W-w$  increases and restores the brake to its first position. The coefficient of friction  $\mu$  can be calculated thus—

Let  $\theta$  = arc of contact (in circular measure) between cord and pulley, then  $\frac{W}{w} = e^{\mu\theta}$

where  $e$  = base of the Napierian logarithms = 2.71828.

The friction surfaces (in contact) of the brake should be as large as possible, in order to readily dissipate the heat generated. Mr. Maw gives the following rule for finding the smallest dimensions of a brake pulley: if H.P. = horse-power to be measured by the brake, and  $v$  = peripheral velocity of the pulley in feet per minute, and ( $b$ ) = width of rubbing surfaces in contact, measured axially, then  $\frac{v}{H.P.} \cdot b$  must not be less than 700.

(7) EFFICIENCY.—This can at once be obtained if the electrical H.P. absorbed by the motor for a given B.H.P. is known. If  $A$  amperes as read off on the ammeter is passing into the machine at a P.D. of  $V$  volts read on the voltmeter placed across the terminals of the machine, then the input or E.H.P. =  $\frac{AV}{746}$  where 1 H.P. = 746 Watts.

Hence the commercial efficiency  $\eta = \frac{\text{B.H.P.}}{\text{E.H.P.}} = \frac{\text{B.H.P.}}{\text{E.H.P.}} \cdot 100\%$ .



(e) **HEATING.**—This may be limited by specification or the question of safety to the conductors, and also considerations of overloading. It is not advisable that the rise of temperature of any part of the machine should exceed  $40^{\circ}$  C. above that of the external atmosphere after a six hours' run on full load. The temperature can be obtained by placing the bulb of a thermometer on the part to be tested and covering it over by some cotton wool. This can only be done to the armature at the moment of stopping, and it will here be noticed that a sudden rise of surface temperature occurs in the armature at the moment of stopping, due, of course, to the ceasing of the ventilating action which goes on while it is rotating (see p. 216).

### (86) Variation of Speed with Voltage across the Armature of a D.C. Electro-Motor (at Constant Excitation).

**Introduction.**—This is an important test, in that it will familiarize the student with the fundamental principles underlying the regulation and control of motors. It can be carried out on a series, shunt or compound-wound motor, so long as the corresponding change in the connections and means for maintaining *constant excitation* are made. As, however, the same result is obtained with each type of motor, we shall operate the test with the simplest type, viz. the shunt motor.

**Note.**—In a series motor the field regulating resistance, at least equal in value to the resistance of the series coils, must be shunted across them; whereas in shunt and compound motors it is connected in series with the shunt coils, and has a resistance and current-carrying capacity at least equal to those of the shunt coils.

**Apparatus.**—Shunt motor, of which  $M$  is the armature and  $F$  the field; main circuit variable rheostat  $R$ , ammeter  $A$ , and switch  $S$ , each capable of dealing with the full-load current of  $M$ ; voltmeter  $V$  and supply mains  $M_1M_2$  of voltage  $E$  each for the rated voltage of  $M$ ; field rheostat ( $r$ ) and low-reading ammeter ( $a$ ); tachometer.

**Observations.**—(1) Connect up as shown in Fig. 91 and adjust the pointers of  $V$ ,  $a$ , and  $A$  to zero if necessary.

(2) With ( $r$ ) all out and  $R$  full in, close  $S$  and gradually cut  $R$  out to short circuit as  $M$  gains speed, then adjust ( $r$ ) to get normal speed ( $n$ ). Note the readings of  $V$ ,  $A$ , and  $a$ , which last-named must now be kept constant throughout the test by varying ( $r$ ).—(See that the lubrication of  $M$  is working).

(3) With the motor still running light as in (2) above, vary  $R$  so as to obtain some eight different speeds ( $n$ ) in about equal steps between 0 and the normal, and note the corresponding readings of  $V$ ,  $A$ , and  $a$  ( $a$  being kept constant throughout).

(4) Repeat (3) with the motor running at full load (if arrangements permit), and for the same value of constant field current ( $a$ ) as before.

**Note.**—The loading-up of motor can most conveniently be effected by means of an eddy-current brake or by taking any desired output from a coupled generator.

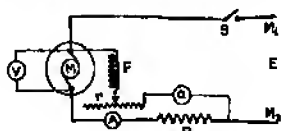


FIG. 81.

(5) Repeat (3) and (4) with, say, half the previous excitation maintained constant and tabulate all your readings as follows—

NAME . . . . . DATE . . . . .  
 Motor No. . . . . Type . . . . . Armature Res.  $r$  = . . . . . ohms . . . . .  
 Full Load:—B.M.P. = . . . . . Volts = . . . . . Amps = . . . . . Exciting Amps. = . . . . .  
 R.P.M. = . . . . .

Motor running Light or Loaded.	Supply Volts ( $V$ ) on Armature.	Back E.M.F. $s = V - A \cdot r$ of Armature.	Armature Amps. ( $A$ ).	Constant Field Amps. used ( $a$ ).	Armature Speed in R.p.m. ( $n$ ).	Calculated Ratios.		
						$\frac{n}{V}$	$\frac{n}{A}$	$\frac{n}{s}$

(6) Plot to the same pair of axes, curves having speed ( $n$ ) as ordinates with values of  $V$ ,  $A$ , and  $\left( \frac{\text{supply voltage across } M_1 M_2}{A} \right)$  as abscissae.

**Inferences.**—State clearly what you can deduce from the table of results and curves, and show how they can be applied

to the design of a main circuit current rheostat for controlling the speed of the motor.

### (87) Variation of Speed with Excitation in a Direct Current Electro-Motor (with Constant Supply Voltage on Armature).

**Introduction.**—The reader should peruse the introduction of the last test, the remarks in which apply to the present test also. In addition, it may be pointed out that when the motor is running light the back E.M.F. will remain nearly constant, since the power required to drive is usually very small, and is  $\propto (V-v)$ , consequently the increase of speed will be almost inversely  $\propto$  to decrease of field strength.

**Apparatus.**—That required for the present test is precisely as detailed for the last one, and need not be repeated again here.

**Observations.**—(1) Connect up exactly as shown in Fig. 91 of the last test, and adjust the pointers of  $V$ ,  $a$  and  $A$  to zero if necessary.

(2) With  $(r)$  all out and  $R$  full in, close  $S$  and gradually cut  $R$  out as the motor gains speed, until  $V$  reads the normal voltage of the motor; then adjust  $(r)$  to get normal speed. Note the readings of  $A$ ,  $a$  and  $V$ , which last-named must now be kept constant throughout the test by varying  $R$  (see that the lubricating arrangements of the motor  $M$  (Fig. 91) are working).

(3) With the motor still running light, as in (2) above, vary  $(r)$  so as to obtain some 8 speeds  $(n)$ , differing by about equal steps between 0 and the normal value, and note the corresponding readings of  $A$ ,  $a$  and  $V$  ( $V$  being kept constant throughout).

(4) Repeat (3) with the motor running at full load (if arrangements permit), and for the same constant value of  $V$  as before.

**Note.**—The most convenient way of loading up  $M$  (Fig. 91) is by means of an eddy current brake, or by taking the required output from a coupled generator.

(5) Repeat (3) and (4) with, say, half the previously normal value of supply voltage  $V$  across the armature, maintained constant, and tabulate as follows—

Name . . . Date . . .  
 Motor: No. . . . Type . . . Armature Res. ( $r_a$ ) = . . . ohms.  
 Field Coil Res. ( $r_f$ ) = . . . ohms.  
 Full load: B.H.P. = . . . Volts = . . . Amps = . . . Field Amps = . . . R.p.m. = . . .

Motor running light or loaded.	Armature			Field Flux x 1/n.	E/n.	Field Current (a).	
	Supply Voltage V (const.)	Amps A	Speed (n)			Ascending.	Descending

(6) Plot to the same pair of axes, curves having speed ( $n$ ) as ordinates with values of ( $A$ ), ( $a$ ) and (supply voltage across  $M_1M_2$ :  $a$ ) as abscissae, and between  $1/n$  as ordinates with ( $a$ ) as abscissae.

**Inferences.**—State clearly what can be deduced from the table of results and curves, and show how these can be applied to the design of a field regulating rheostat for controlling the speed of the motor.

### (88) Variation of Voltage, Current, and Speed, with position of the Brushes around the Commutator of a D.C. Machine at Constant Excitation.

**Introduction.**—Although the usual practice now is to design D.C. generators and motors with a fixed diameter of commutation and immovable brush-bars, special cases are met with in which provision is made for moving the brushes through considerable angular space round the commutator. As is well known, the terminal voltage of a generator and the speed of a motor is each capable of variation by moving the brushes, while a motor can even be stopped and reversed by so doing. In fact, where the variation of voltage or speed required is not large, it can be obtained by brush movement without expensive field regulators and without altering therefore the field strength—a feature which is sometimes valuable, while most machines will admit of quite an appreciable brush movement without much sparking, when running light, such is not the case when they are running on load, so that the scope of this test may be limited by the amount of sparking. Further, it will be found easier to

apply the test to a motor than to a generator, and we shall therefore operate the present test on a motor.

**Apparatus.**—Shunt motor, of which  $M$  is the armature and  $F$  the field; main circuit variable rheostat ( $R$ ); ammeter  $A$ , and switch  $S$ , each capable of dealing with the full-load current of  $M$ ; voltmeter  $V$  and supply mains  $M_1M_2$  of voltage  $E$  at least

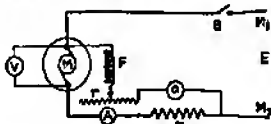


FIG. 92.

equal to the normal for  $M$ ; field rheostat  $r$  and low reading ammeter ( $a$ ); tachometer and, if possible, some scale for indicating the angular motion of the brushes round the commutator.

**Observations.**—(1) Connect up as in Fig. 92, adjusting ( $V$ ) ( $A$ ) and ( $a$ ) to zero if necessary, and ( $R$ ) to a value not less than the Ratio  $\frac{\text{supply voltage}}{\text{full-load current}}$  ohms, so as to prevent the full-load motor-current being exceeded if the armature comes to rest or its speed increasing too rapidly as the brushes are moved.

**Note.**—This value of  $R$  will be given by blocking the armature and with normal excitation, noting the value necessary to give full-load current on  $A$ .

(2) Start the motor either by using the ordinary "Starter," or by ( $R$ ) temporarily increased before closing  $S$ , and then gradually cutting out  $R$  until normal speed is reached—the brushes being in the normal full-load running position, and the excitation adjusted to normal full-load value.

Now note the values of  $V$ ,  $A$  and ( $a$ ), and the speed.

(3) Next keeping ( $a$ ) constant at the above value, adjust  $R$  to the minimum value allowable and found in obs. (1), and note the readings of  $V$ ,  $A$  and speed for normal position of brushes (as in obs. 2), and for a series of different positions throughout an angular distance =  $\frac{1}{2}$  the polar pitch either side of their normal position.

(4) Repeat (3) at the nearest B.H.P. load to full load which it is practicable to run at, and tabulate as follows—

Name . . .		Date . . .	
Motor: No. . . .		Type . . .	
Full load B.H.P. = . . .	Amperes = . . .	Volts = . . .	R.p.m. = . . .
Armature Resistance $r_a$ = ohms.	Normal Excitation = amperes.		

Position of Brushes.	Speed in revs. per min. (n).	Armature		Back E.M.F. (e) $E - A_a r_a$	Field Strength $= e/n$ .
		Volts $V$ .	Amperes $A$ .		

(5) Plot curves on the same axes having values of brush position (normal as origin) as abscissa with values of  $e/n$ ,  $V$ ,  $A$  and speed respectively as ordinates.

**Inferences.**—State clearly what can be deduced from the results of your test.

### (89) Efficiency and B.H.P. of Direct Current Series Wound Electro-Motors.

**Introduction.**—The series motor in general possesses some characteristic features which it may be well here to note in view of the prominent place this type of motor has, and still is, taking in electric traction and power work generally. Since it can be shown that the torque  $T$  of the motor is given by the relation—

$$T = \frac{CNA_a}{2\pi} = \frac{CN}{2\pi} \frac{E - e}{r_a} = \frac{CN}{2\pi} \frac{E - CNA_a}{r_a}$$

where  $C$  = number of armature conductors all round,

$N$  = number of lines threading the armature or the useful flux,

$A_a$  = number of amperes of current through armature,

$E$  and  $e$  = impressed and back E.M.F.s of the mains and motor respectively,

$n$  = speed in revs. per second,

and  $r_a$  = resistance of armature circuit.

It will be at once evident that the torque exerted is a maximum at starting, i.e. when  $n = 0$ , and that it varies as the armature current  $A_a$ , since  $N$  also varies as  $A_a$ .

Again, when the motor is "running light" at its maximum speed  $T = 0$  nearly, for then the back E.M.F. generated almost = that of the mains  $E$ .

Thus a series motor tends to race directly the load is

R

suddenly removed, which is an undesirable feature for workshop driving.

The fact that  $T$  = maximum at starting, and that the motor will start on full load, is a most valuable property for traction work on tram and railway lines.

In the following Fig. and all after it, the motor is represented symbolically, (a) denoting the armature, commutator, and brushes, and *FM* the field magnet coils, which in this case, being series wound, are represented by a few curly lines.

**Apparatus.**—Electromotor (series wound) to be tested, fitted with an absorption dynamometer or brake (Fig. 295); ammeter *A*; voltmeter *V*; variable rheostat *R* (p. 606); switch *S*; battery or dynamo *B*, giving the requisite voltage needed for the motor, and speed indicator and set of half-pound and one pound weights for the brake, also a lubricant if necessary.

**Observations.**—(1) Connect up as indicated in Fig. 93, and adjust the pointers of *A*, *V*, and the tachometer to zero if necessary. See that all lubricating cups in use feed slowly and properly.

(2) See that *R* is at its full, then carefully remove the brake from the pulley and close *S*. Take a series of *gradually ascending and descending* observations (by varying *R*) for about ten different speeds, ranging by

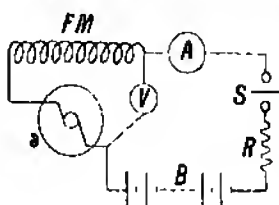


FIG. 93.

about equal intervals between the lowest readable on the tachometer and the maximum safe speed for the motor, noting this speed and the corresponding values of *A* and *V* at each.

(3) Replace the brake and repeat 2 for no weight in the pan. From 2 and 3 the loss in Watts in the brake can be found.

**Note.**—It will probably be necessary to exert a *very small* pressure by the finger on the brake in 3 to prevent it being carried round as the pulley rotates. No appreciable error need be introduced due to this. If a form of brake is used in which no loss of power can occur other than that incidental to its

use when actually measuring power, then omit obs. 3 and also the last seven columns in the next table, and substitute a column headed  $A_1 V_1$  watts to run motor at no load.

Tabulate your results as follows—

Speed Revs. per min. (s).	Without Brake.						With Brake.						Loss in Brake in Watts $H_B =$ $(A_2 V_2 - A_1 V_1)$
	Volts.			Amperes.			Volts.			Amperes.			
	Ascending.	Descending.	Mean $V_1$ .	Ascending.	Descending.	Mean $A_1$ .	Ascending.	Descending.	Mean $V_2$ .	Ascending.	Descending.	Mean $A_2$ .	

(4) With the brake carefully replaced on the pulley and the smallest weight in the scale pan, close  $S$  and by varying  $R$  adjust the speed to the lowest convenient. Note this and the reading of  $V$  and  $A$  simultaneously, and the weight.

(5) Repeat 4 at the same constant speed for ten or twelve loads or weights in the pan, ranging from the smallest to that which will cause the current to rise to not more than 25% over normal.

(6) Repeat 4 and 5 for the maximum allowable speed and an intermediate one, each constant throughout, and tabulate your results as follows—

NAME . . . . . DATE . . . . .  
 Motor tested: No. . . . . Type . . . . . Maker . . . . . Weight . . . . .  
 Resistance: Armature  $r_a = \dots$  ohms. Series coils  $r_s = \dots$  ohms.  
 Effective radius of Brake pulley and band  $r = \dots$  ft.  
 Normal B.H.P. = . . . . . Amperes = . . . . . Volts = . . . . . Speed = . . . . . revs. per min.

Speed Revs. per min. (s).	Weight on Pan (lbs.)	Lever Spring balance reading (lbs.)	Net Torque $T =$ $(W - w) r$ (pound feet).	Volts $V_2$ .	Amperes $A_2$ .	Total H.P.		Commercial Efficiency $= \frac{H_1}{H_2} 100\%$
						absorbed $A_2 V_2 = H_2$ $\frac{746}{33000} \times 746$	developed $H_1 =$ $\frac{H_2}{\eta}$	

Note.—The true H.P. developed = H.P. calculated + H.P. lost in brake itself.

(7) With the brake removed from the pulley and  $R$  full in, close  $S$  and obtain the maximum speed allowable. Note this and also simultaneously the amperes ( $A_1$ ) and volts ( $V_1$ ).

(8) Replace the brake and add weights to the pan so as to obtain about ten different loads to the point when the largest load



stops the motor. Note the current  $A_4$  and speed ( $n$ ) at each, the volts  $V_1$  having been kept constant by altering  $R$  to suit the load.

**Note.**—The current should not exceed about 40% above the normal. Tabulate your results as above.

(9) From observations 2 and 3 plot the following curves between

(a) Volts  $V_1$  as ordinates and the corresponding speeds ( $n$ ) as abscissae.

(b) Brake loss  $W_s$  as ordinates and the corresponding speeds ( $n$ ) as abscissae.

From observations 4–6, plot for each speed curves between

(c) Efficiency and current as ordinates and corresponding B.H.P.s as abscissae.

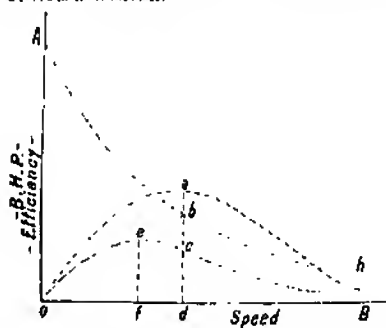


FIG. 91

From observations 7 and 8 plot the following curves between

(d) The speed in each case and E.H.P. input, B.H.P., and efficiency.

(e) The speed and current as ordinates and torque as abscissae.

(10) Calculate the coefficient of friction ( $\mu$ ) between the brake band and pulley for various loads and for the arc of contact employed.

From the curves 9 (d) deduce the relation between the speeds that give maximum efficiency and maximum B.H.P. respectively.

**Inference.**—State very clearly all the inferences deducible from your experimental observations. Explain fully the curves obtained in 9 (d) above.

**Note.**—The general form of the curves (d) 9 above are shown

in Fig. 91. The diagram due to Mr. Kapp is an exceedingly useful one for seeing the relative H.P.s and efficiency.  $OaB$  is the B.H.P. curve,  $OaB$  is the efficiency curve, and  $Akk$  is the E.H.P. (input) curve. The shape of this last varies with the type of series motor run off constant potential mains. The ordinates, such as  $(ad)$ , of the efficiency curve  $OaB = \frac{ed}{bd}$  at this and similar points to any arbitrary scale of ordinates.

### (90) Efficiency and B.H.P. of 500 Volt Direct Current Series-Wound Tramway Motors.

**Introduction.**—The particularly heavy and trying work which a tramway or railway motor has to perform renders it all important to subject the machine to the most searching tests for defects or other faults at the outset. Such tests are twofold—

(1) A complete test of the motor at the works of the makers and again when fixed to the car.

(2) A test of its performance when driving the car on some approved route on the system. With regard to this case, the worst route of the whole system is chosen, i.e. one having the steepest gradients and sharpest curves.

The car is loaded with an artificial load, such as sand bags, for instance, equal to the full load of passengers which it is intended to carry. It is then run as continuously as possible along that route with five seconds stops every five minutes for say two hours.

This test is considered satisfactory, if, at the end of that time, all has gone on satisfactorily and the temperature of the armature and commutator of the motor has not risen above the prescribed limit.

Next, with regard to the "Works Tests." Besides the efficiency test at various loads, the motor should be run at the average speed it will run at in practice, say that corresponding to eight or nine miles per hour of the car, for four to six hours at the maximum load which the motor is intended for.

Except in the case of electric railways, where the car or engine axle is direct driven, single reduction gear between motor and car axles is almost universally employed of between 4.75 and 4.85 to 1.

The sizes of tramcar wheels are usually either 30 inches or 33 inches in diameter. The remarks mentioned in the *Introduction of Test 89* should be carefully read and remembered, when the performance of the motor on test will at once be obvious.

**Caution.**—*The operators of the controlling rheostat switch-gear, etc., must stand on the india-rubber mat provided, and must on no account touch any live metal work on the circuit of the 500 volt generator and tramway motor.*

*Great care must be taken to insure that the rheostat in the main circuit of the motor is FULL IN before closing the main switch, and also that it is at once re-inverted before pulling out that switch on stopping.*

The apparatus and connections of the preceding test are those now to be obtained, and the observations, as there given, to be carried out. In addition to curves 9,  $a-e$ , plot two on the same curve sheet, having speed as abscissas, and both torque and amperes as ordinates.

### (91) Relation between the Starting Torque and Current in a D.C. Electro-Motor.

**Introduction.**—It is very instructive to compare the results obtained in applying the principle of the present test to series, shunt, and compound wound motors, but it may also be applied to alternating current motors. The torque or turning effort by the armature on its shaft, measured in terms of a pull, acting at a given radius or lever-arm from the shaft centre, and tending to turn it, is expressed in pound-feet, usually, in this country. In a motor it results from the interaction of the field magnets and the field of the armature as set up by the currents flowing through it, and is  $\propto$  to the product of these two field strengths.

If  $C$  = the number of effective conductors on the armature;

$N$  = the effective magnetic flux cut by them or flowing in the core;

$A$  = the armature current;

then it can be shown that the torque ( $T$ ) is given by the relation

$$T = \frac{CN}{8.52 \times 10^4} \times A. \quad \text{lb. ft.}$$

an expression independent of the speed of the motor.

$$\therefore T \propto \text{armature current} \times \text{field flux} \propto AN.$$

In a series motor, the field flux  $N$  will vary as  $A$  varies, up to the point of magnetic saturation of the field magnets, when it will be practically constant. Any further increase in  $A$  will give the relation

$$T \propto A.$$

This also holds for a shunt motor, in which the field excitation is practically constant and near saturation.

In a compound or differential motor, however, the shunt and series windings oppose each other magnetically, and hence on starting it may happen that they nearly balance, thus giving practically zero starting torque.

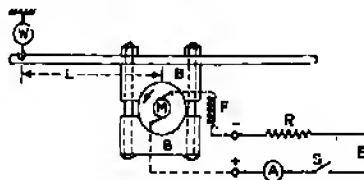


FIG. 95.

In capstan, windlass, and all traction work, maximum torque is required on starting; and since the series motor fulfils this condition and is exclusively used for the purpose in D.C. work, we will consider this type of motor to be the one used in the present test.

**Apparatus.**—Series motor  $M$  to be tested on a suitable D.C. supply  $E$ ; brake-blocks  $B$  with yard-arm  $L$  and spring balance  $W$ ; ammeter  $A$ ; switch  $S$ ; and variable current rheostat  $R$ .

**Observations.**—(1) Connect up as in Fig. 95, setting  $A$  and  $W$  to zero if necessary. Clamp  $B$  to the pulley of the motor so as to prevent slipping (rotation), and with the yard-arm horizontal. Attach the spring balance  $W$  at a measured distance  $L$  from the pulley centre.

(2) With  $R$  full in, close  $S$ , and adjust  $R$  so as to give some ten currents through  $M$  and  $A$  differing by about equal amounts

between  $O$  and the full-load current of  $M$ , noting the readings of  $W$  and  $A$  at each.

**Note.**—The connections of field  $F$  and armature of  $M$  must be such that the latter *tends* to turn in the direction shown. Also the yardarm may have an equal overhang as shown, or be otherwise balanced when horizontal.

Further, as there will be a good deal of static friction at the motor bearings, the armature should be rotated by hand a few revolutions before attaching  $B$   $B$ , so as to well oil the journals; and even then the *mean* of several readings of  $W$ , taken for each value of  $A$  by disturbing the position at which ( $B$ ) rests, by the hand.

(3) Take an ascending and descending series of value of  $A$ , and tabulate as follows—

Motor: No. . . .	Type . . .	B.H.P. = . . .	Volts = . . .	Amperes = . . .
Amperes ( $A$ )	Pull $W$ (lbs.)	Torque $T = W \cdot L$ , lb. ft.	Values of $A/T$	
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(4) Plot a curve having values of  $A$  as ordinates, and  $T$  as abscissae.

**Inferences.**—Point out all that can be deduced from the table of results and shape of the curve.

## (92) Efficiency and B.H.P. of Direct Current Shunt-Wound Electro-Motors.

**Introduction.**—If a shunt motor, supplied at constant potential, has a very low armature resistance, high shunt coil resistance and field magnets giving a field relatively very much more powerful than that due to the armature, the variation of "lead" of the brushes will be slight and the motor will be almost self-regulating in speed for wide variations of load, *i. e.* it would run at constant speed independent of the torque. The falling off of the speed in shunt motors as the torque increases will be the less as the field magnetism is the more powerful. The brushes, in two pole machines, should press at opposite ends of a diameter, and to ensure sparkless running must have a "backward lead." In all

cases the efficiency = total power given out  $\div$  total power put in, both being reckoned in similar units. The input is easily deduced from ammeter and voltmeter readings, but the output is more difficult to obtain accurately. In the present test it is obtained by means of an "absorption dynamometer," which we will assume to be the modified form of Prony Brake introduced by Raffard. Such a brake wastes in heat all the power given out by the motor through friction, but at the same time forms a measure of this power. The arrangement is such that the brake automatically adjusts itself to variations of the coefficient of friction between the rubbing surfaces due to heat. In brake tests of this nature just sufficient lubrication (such as soap and water) and no more ensures smooth working without sudden jerks due to seizing, and this, together with experience in manipulation, is the secret of the success of such tests.

If  $(r)$  = mean effective radius of pulley and band together in ft.,  $n$  = number of revs. per min.,  $W$  = weight in lbs. in scale pan, and  $w$  = weight in lbs. at the slack side of the pulley; then the angular velocity of the pulley  $\omega = 2\pi n \div 60$ , and the couple or torque resisting motion  $T = (W - w)r$ ; then the work done per sec. =  $\omega T$ , and the B.H.P. =  $(W - w) 2\pi rn \div 33000$ .

**Apparatus.**—Shunt motor ( $M$ ) to be tested; voltmeter  $V$ ; ammeters  $A$  and  $a$ ; rheostats  $R_1$  (p. 606) and  $R_2$  (p. 599); switches  $S_1$  and  $S_2$ ; source of current  $B$ ; speed indicator. A set of  $\frac{1}{2}$  lb. and 1 lb. weights are provided with the brake, together with a pump and tank by means of which a slight dripping of lubricant may be allowed to fall into the central rotating pulley and band.

**Note.**—For further remarks on the testing of motors see the "General Introduction" on the subject, p. 232, *et seq.*

**Observations.**—(1) Connect up as indicated in Fig. 96 and adjust the pointers of all the instruments to zero where necessary. See that all lubricating cups in use feed slowly and properly.

(2) Uncouple the absorption dynamometer from the motor shaft. Set  $R_1 R_2$  at their maximum values, and close  $S_2$ , adjusting the exciting current ( $a$ ) to the normal value by means of  $R_2$ .

(3) Close  $S_1$  and take a series of *gradually increasing and decreasing* observations (by varying  $R_1$ ) for about ten different

speeds ranging by about equal intervals between the lowest readable on the tachometer and the maximum allowable for the motor in question, at *constant normal excitation*, noting the speed and corresponding values of  $A$  and  $V$  at each.

(4) Repeat 2 and 3 for exciting currents (a) 50% below and 20% above normal respectively.

(5) Re-couple the brake and motor together and repeat 2-4 for no weight in the pan. From 2-5 the loss in Watts in the brake can be found.

N.B.—It will probably be necessary to exert a very small pressure by the finger on the brake in 5 to prevent it being

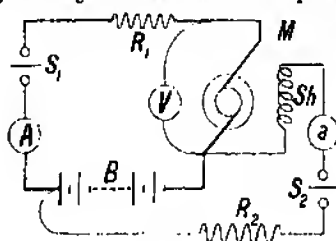


FIG. 96.

carried round as the pulley rotates. No appreciable error need be introduced due to this. Tabulate<sup>1</sup> your results as follows—

Speed Revs. per min. (n)	Exciting current Amps. (a)	Without Brake.					With Brake.					Loss in Brake in Watts $W_b =$ $(A_2 I_2 -$ $A_1 I_1)$	
		Volts.			Amps.		Volts.			Amps.			
		Ascending.	Descending.	Mean $V_1$ .	Ascending.	Mean $A_1$ .	Ascending.	Descending.	Mean $V_2$ .	Ascending.	Descending.		Mean $A_2$ .

<sup>1</sup> If a form of brake is used in which no loss of power can occur other than that incidental to its use when measuring power, then omit cols. 8 and also the last 7 columns in the above table and substitute a column headed  $A_2 V_1$  Watts to run motor at b load.

(6) Adjust both the exciting current (a) and the speed (n) to the normal for the motor being tested and keep both *constant*, then take a series of readings of  $A_2$  and  $V_2$  for some ten different loads varying from the smallest weight in the pan to the one which will give an armature current not exceeding 25% over normal.

- (7) Repeat 6 for a 50% smaller excitation at the same speed.  
 (8) Repeat 6 and 7 for a 50% smaller speed.  
 (9) For a constant voltage across the armature maintained by means of  $R_1$ , load the brake with different weights, and note these and the corresponding speeds and currents through the armature at constant normal excitation, and tabulate as follows—

NAME . . . . . DATE . . . . .  
 Motor tested: No. . . . . Type . . . . . Maker . . . . . Weight . . . . .  
 Resistance—Shunt coils  $r_s = \dots$  ohms. Armature  $r_a = \dots$  ohms.  
 Effective radius of brake pulley and band  $r = \dots$  ft.  
 Current in Shunt coils  $s_s = \dots$  amps.

Speed in Revs. per min.	Weight in lbs. $W$	Lower weight $w$ (lbs.)	Net Torque $T_m$ (lb.-ft.)	Total H.P. developed $\frac{2\pi n T_m}{33,000}$	Armature Amperes $A_a$	Volts $V_a$	Total H.P. absorbed $\frac{A_a V_a}{746}$	% efficiency $\frac{H.P. dev.}{H.P. abs.} = 100 \frac{H_1}{H_2}$

Note.—The true H.P. developed = H.P. calculated + H.P. lost in brake itself.

(10) From experiments 2-5 plot curves between, volts  $V_1$  as ordinates, and speed ( $n$ ) as abscissa, also with brake loss as ordinates and speed as abscissa.

From experiments 6-8 plot curves for each speed, having efficiencies as ordinates and total H.P. developed as abscissa, also between the latter and speed as ordinates.

From experiment 9 plot the mechanical characteristic curve, having speed and current as ordinates and torque as abscissa.

Inferences.—What can you deduce from the results of your experiments, especially from observation 9?

### (93) Efficiency and B.H.P. of Direct Current Compound Wound Electro-Motors.

Introduction.—The Compound Wound motor is an automatically self-regulating one for maintaining constant speed independently of the magnitude of the load.

Without considering the theory of this regulation, which is outside the province of the present work, and for which the reader should refer to standard theoretical works, it may be



remarked that the desired result is obtained by employing the series and shunt coils to magnetize the field magnets differentially, i. e. while the shunt magnetizes, the series coils *de-magnetize*. This differential compounding results in the production of a nett field at any particular load sufficiently greater than what would be given by an equivalent pure shunt motor to cause the back E.M.F. to rise sufficiently to maintain the speed constant. The efficiency of such motors cannot manifestly be so high as one of the same size which is not wound in this way, since an extra amount of power is used up in producing the demagnetizing force which actually destroys part of the field.

**Apparatus.**—Precisely similar to that required for the shunt motor test (p. 248).

**Observations.**—These are the same as for the above-mentioned shunt motor test, and will not consequently be repeated here.

The experimenter should refer to and carry the present test out in the same way, but in coupling up at the onset, care must be taken to connect so that the series coils oppose the shunt and tend to demagnetize the magnets. Exactly similar tabulation of results and plotting of curves must be carried out with the inferences deducible.

N.B.—The applied E.M.F. to the motor should be maintained constant.

#### (94) Efficiency and B.H.P. of *Small* Direct or Alternating Current Electro-Motors. (Cradle-Balance Method.)

**Introduction.**—In testing small motors, such as from  $\frac{1}{10}$  to  $\frac{1}{2}$  of a H.P., difficulties present themselves in measuring the power developed by them or the work which they will do, owing to the relatively large amounts of extraneous friction introduced in applying the usual brake tests. In fact, in the case of the smaller power motor, this source of friction would entirely vitiate the results and make them worthless. The following method practically gets over this difficulty entirely, and may be carried out in one of two ways—

(a) The motor to be tested is suspended freely with its armature spindle in centres, or on friction wheels, the field magnet

system with its bed-plate, etc., being carefully *balanced* by counterpoise weights so as to bring the centre of gravity of the system in a line with the spindle. On the motor being supplied with electrical energy, and made to rotate and do work against the friction introduced at the face of its pulley, by a stretched cord passing once round, the armature reacts on the field magnets tending to rotate them in the opposite direction with a certain force.

If then this action is resisted by a weight or force  $W$  attached to the field magnet system at a leverage  $L$ , then the moment of this force resisting the tendency, i. e. the torque, =  $WL$ .

Thus the arrangement is practically an electro-magnetic dynamometer in which the magnetic friction between armature and field magnets takes the place of mechanical friction in the ordinary dynamometer.

The preceding arrangement of the method has the disadvantage that the weight of the heaviest portion of the machine is resting on the shaft, and consequently there will be a bearing friction assisting the magnetic pull of the armature on the field.

A better arrangement in this respect is one devised by Prof. C. F. Bracket, which is merely a slight modification of the preceding one. It consists in fixing the motor in a "*cradle*" supported freely by knife edges resting on steel or agate planes, or on friction rollers, carried in a suitable fixed frame. The whole suspended system is very carefully balanced by means of counterpoise weights so that the centre of gravity lies in the axis of the motor shaft, this latter having been set in a line joining the knife edges of the cradle.

A horizontal balanced lever controls the cradle, the end of it either supporting weights or being attached to a spring balance. Thus it will be seen that now the weight of the armature only is on the bearings, and it is being used under ordinary conditions. The balanced lever might be graduated and a sliding weight used to run along it to balance the torque, but the arrangement of the spring balance shown in Fig. 285 is the simplest and easiest to manipulate. This method has a further advantage that the friction at the journals of the motor does not affect or vitiate the measurement, but in the case of the application to a dynamo it should be remembered that it does. It should be borne in mind

that a fruitful source of error may arise due to loss of power in driving the speed indicator. When small motors are being tested, care should be taken to choose an indicator that is very easily driven, and to drive it by means of a spiral or helical spring of, say, thin hard-drawn brass. Any eccentricity between the two shafts does not then matter so much as it would if they were direct coupled.

**Apparatus.**—That required for this test is precisely similar to what is detailed under one or other of the preceding methods of testing series, shunt, or compound wound direct current motors or alternating current single phase motor, according to which of these types of motors the one being tested belongs. In addition the cradle absorption dynamometer is needed, for a complete description of which see p. 621.

**Observations.**—As, with the exception of the somewhat different type of brake herein to be manipulated, the whole test will be precisely similar to one of the foregoing motor tests, depending on which kind of electromotor is to be tested, the *rationale* of this present test will not be repeated here. The experimenter should refer to the proper corresponding test and carry out the present one in an exactly similar manner, tabulating and plotting the results in just the same way.

Though the following expression will be found in connection with the description of the cradle dynamometer on p. 621, we may repeat that if  $W$  = weight or force applied at the end of the cradle lever in order to keep the same at zero when the motor is doing work, and if  $L$  = distance between its point of application and the fulcrum of the cradle, then the torque exerted by the motor =  $WL = T$ , and the work it does per sec. =  $\omega T$  =  $2\pi nT$ .

Where  $n$  = speed in revs. per sec.—

$$\therefore \text{H.P. developed} = \frac{2\pi nT}{550}$$

Consequently if different tensions are applied on the cord wrapped round the motor pulley, causing it to do various amounts of work, thereby taking in different currents ( $A$ ) amps. at different voltages  $V$ , the efficiency of the motor at each load is—

$$\text{Efficiency} = \frac{\text{H.P. developed}}{\text{H.P. absorbed}} = \frac{2\pi nT \times 746}{550 \times AV}$$

### (95) Efficiency and B.H.P. of Direct Current Electro-Motors by Swinburne's Electrical Method.

**Introduction.**—In the usual brake tests it is difficult and often impossible to obtain very accurate results, owing to variation of the co-efficient of friction between the rubbing surfaces and the resulting jorky behaviour of the brake. The advantage of any method, therefore, of measuring the input and output of a motor by solely electrical means will at once be apparent, as it is possible to obtain much more accurate results with such a method.

The present method, which is purely an electrical one, is due to Mr. James Swinburne, and is sometimes termed the "*Stray Power*" method. The principle of it and all similar methods is based on the fact that

Total Power given out = Total Power put in - Power lost internally, or in symbols,  $W_o = W_i - W_L$ ; where the suffixes  $O, I$ , and  $L$  denote the *output*, *input*, and *total losses* in Watts ( $W$ ) respectively.

We thus at once obtain the commercial efficiency of the motor to be  $\frac{W_o}{W_i} = \frac{W_i - W_L}{W_i}$ .

The input in Watts  $W_i$  given to the motor is at once obtained by the product of the volts and amperes of the supply. The total loss  $W_L$  in Watts we will consider now more in detail, and which in any machine is made up as follows: (a) the copper losses  $L_c$  in armature and exciting coils due to heating by the passage of current, and which can easily be calculated when the currents and resistances are known; (b) the friction losses  $L_f$  due to air churning, journal and brush friction; (c) magnetic frictions or iron losses  $L_m$  due to eddy or Foucault currents and magnetic hysteresis.

Hence total internal loss  $W_L = L_c + L_f + L_m$ , and to the sum ( $L_f + L_m$ ) Mr. Swinburne has given the somewhat appropriate name of "*Stray Power*." The copper losses are calculable as follows—

Let  $C$  = total current flowing into the motor from the supply, and let  $R_a, R_{se}$  and  $R_{sh}$  be the resistances of the armature, series

coils, and shunt coils respectively of any motor of which  $R_{sh}$  can be measured by a Wheatstone Bridge, and  $R_a$ ,  $R_m$  by the "Potential Difference" method (p. 84) or ammeter and voltmeter method, p. 86. Then we shall have for a

Series motor  $I_C = C^2 (R_a + R_m)$ ,

Shunt motor  $I_C = \frac{V^2}{R_{sh}} + \left(C - \frac{V}{R_{sh}}\right)^2 R_a$ , where  $V$  = normal working voltage,

Compound motor (long shunt)

$$I_C = \frac{V^2}{R_{sh}} + \left(C - \frac{V}{R_{sh}}\right)^2 (R_a + R_m),$$

Compound motor (short shunt)

$$I_C = C^2 R_m + \frac{(V - CR_m)^2}{R_{sh}} + \left(C - \frac{(V - CR_m)}{R_{sh}}\right)^2 R_a$$

The remaining losses, i.e. the stray power ( $L_F + L_m$ ), can readily be obtained by running the motor at no load, i.e. with no other load than its own friction, eddy currents and hysteresis, at normal excitation of the field. Then we have

$$(L_F + L_m) = AV_a - A^2 r_a = \text{Stray Power,}$$

where  $A$  now = current flowing into the motor armature at voltage  $V_a$  across the armature, and  $A^2 r_a$  is the copper loss in the armature occurring for this current and voltage.

**Note.**—Only quite a small current at the normal voltage of the motor is required to be furnished by an auxiliary source of E.M.F., and if  $R_a$  is very small,  $A^2 r_a$  can be neglected in comparison with  $AV_a$  in this last formula.

**Apparatus.**—Motor  $M$  to be tested, which for purposes of discussion merely we will assume is shunt wound; voltmeter  $V$ ;

low reading long scale ammeter  $A$ ; rheostat  $R$  (p. 606); tachometer; complete Wheatstone Bridge set (W.B.); two-way voltmeter key  $K$  (p. 587); switch  $S_2$ ; source of E.M.F. ( $E$ ) at least equal to that for which the motor was built; rheostat  $r$  (p. 599) in the field coil circuit.

**Observations.**—(1) Connect up as in Fig. 97, and adjust the instruments  $V$  and  $A$  to

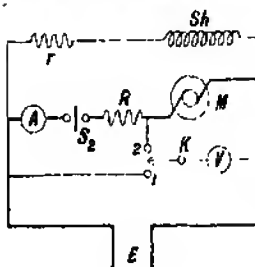


FIG. 97.

zero if necessary. Insert  $E_1$  when the field should then be excited to the normal amount, which can be seen by closing  $K1$  and noting whether the normal voltage is read off on  $V$ .

(2) With  $R$  at its *maximum value* (not less than about 10 ohms), close  $S_2$ , adjusting  $E$  and if necessary the excitation by the rheostat  $r$ , so that the machine runs at its normal speed. Now note, by closing  $K2$ , the volts  $V_a$  across the armature terminals and the current  $A$  amps. flowing through it.

(3) Repeat 2 at the same excitation for some ten different speeds in all, both below and above normal, and tabulate as shown.

(4) Open  $E$ ,  $S_2$  and  $K$ , and measure by suitable means the resistance  $R_a$  of the armature and  $R_{sh}$  of the shunt, remembering of course to disconnect one from the other at the time.

(5) Calculate the B.H.P. and commercial efficiency of the motor at *normal voltage*  $V$  for some ten different assumed values of current  $C$  supplied to the machine ranging from 0 to full load by about equal increments, and tabulate as shown in the larger table.<sup>1</sup>

Speed in R.p.m.	Stray Power Readings (from obs. 2 and 3)			Total Intake Watts Including Light $\Delta V_a$
	Volts $V_a$	Amps. $A$	Watts $\Delta V_a \cdot A$	

NAME . . .

DATE . . .

Motor tested: No. . . Normal Voltage = . . . Volts. Resistance: Armature = . . . Ohms.

Type . . . " Current = . . . Amps. Shunt = . . . "

Maker . . . " Speed = . . . Revs. per min. Series = . . . "

Normal Speed Revs. per min.	Power supply assumed for calculation.		Stray Power Measure- ment in Obs. 2.		Losses.		Calcu- lated Output $W_o =$ $W_i - W_L$	Commercial Efficiency $= 100 \frac{W_o}{W_i} \%$
	Volts $V$	Amps $C$	Total Input $W_i =$ $V \cdot C$	Volts $V_a$	Amps $A$	$I_a + I_{sh}$ $= A V_a$ $= A^2 R_a$ Watts	Copper Loss (calcu- lated) $(I_a + I_{sh})^2 R_a$	

(6) Plot the following curves having

(a) Efficiency as ordinates and output  $W_o$  as abscissas.

(b) Stray power as " and speed as "

(c) Output  $W_o$  as " and input  $W_i$  as "

**Inferences.**—State very clearly all that you can infer from the above experimental results.

<sup>1</sup> See note to larger table, p. 222-3.

### (96) Efficiency of Direct Current Electro-Motors by Poole's Electrical Method.

**Introduction.**—This method,<sup>1</sup> due to Mr. Cecil P. Poole, is an electrical one entirely, and enables the efficiency of an electro-motor to be obtained without using an absorption brake. The rated B.H.P. of the machine is assumed for the purposes of calculation, and the whole essence of the test consists in obtaining the armature current at which this rated output is obtained.

Let  $A$  be this full load armature current.

$V$  = the normal voltage which the motor should have.

$W$  = the normal rated B.H.P. of motor, reckoned in Watts,  $v$  and  $a$  = the measured quantities as detailed below.

Then the armature core + friction losses  $w = (V - v)a$  Watts,

and the armature resistance  $r = \frac{v}{a}$  ohms.

$$\text{Hence } A = \frac{V - \sqrt{V^2 - 4(W + w)r}}{2r} = \frac{V}{r} \left( 0.5 - \sqrt{\frac{1}{4} - \frac{(W + w)r}{V^2}} \right)$$

This value for  $A$  is based on the assumption that the core losses, armature friction, windage, and eddy currents in the pole pieces all remain constant from 0 to full load. While this is not strictly the case, the error introduced is practically negligible.

**Apparatus.**—Suitable source of supply of slightly higher voltage than the normal required for the motor to be tested; rheostat p. 599; low-reading long scale ammeter ( $a$ ); voltmeter  $V$  to read the normal voltage; low-reading long-scale voltmeter ( $v$ ); and if the motor is shunt or compound wound, an ammeter to measure the normal shunt current  $a_{sh}$ ; switch.

N.B.—If the resistance of the shunt  $r_{sh}$  be known, then the last-named ammeter may be dispensed with for  $a_{sh} = \frac{V}{r_{sh}}$  amperes.

**Observations.**—(1) Connect up the above apparatus so that the rheostat and ammeter ( $a$ ) are in series with the armature alone, and the switch, so that it cuts off the supply entirely from motor and all apparatus, the voltmeter  $V$  being across the armature terminals, the shunt coils of the motor being across the mains.

<sup>1</sup> The rationale of the method first appeared in the *American Electrician*, to which the author is indebted for it.

(2) With the rheostat *full in*, close the main switch when the shunt will at once be fully excited. Now gradually cut out resistance in the armature circuit, thereby running up the speed, until  $V$  reads the normal voltage across the armature, thus running light. Now note the small armature current ( $a$ ) amperes flowing.

(3) Switch off the shunt circuit and block the armature to prevent it moving. With the rheostat *full in*, close the main switch and again pass the same current ( $a$ ), as in observation (2) above, through the armature while stationary, noting the corresponding fall of potential ( $v$ ) volts across the armature terminals by means of the low-reading voltmeter, and switch off.

(4) Repeat observation (2 and 3) twice or three times and take the mean of the respective values of ( $a$ ) and ( $v$ ), calculating the efficiency  $\Sigma$  of the motor on full load from the relation —

$$\Sigma = \frac{100 W}{V(A + a_{sh})} \%$$

and tabulate your results as follows—

NAME . . . DATE . . .  
 Motor Tested; No . . . Maker . . . Rated H.P. . .  
 Normal Voltage . . . Speed = . . . Current . . .  
 Resistance: Armature = . . . Shunt = . . . Rheostat = . . .

Armature Current on running free, ( $a$ ) amperes	Voltage across Armature Shunt ( $v$ )	Losses ( $V \times a$ ) w	Armature Resistance $r = \frac{v}{a}$	Field Current $a_{sh}$	Full load Armature Current $A$	Efficiency of Motor $\Sigma$

**Inferences.**—State clearly any advantages or disadvantages which you consider the method possesses.



### General Considerations Relative to the Testing of Asynchronous Alternating Current Induction Motors.

While it is not proposed to discuss either the construction or the theory of action of such machines, certain considerations relative to the testing of both single and polyphase induction motors may with advantage be noted. In all cases they are self-starting by reason of the *rotating magnetic field* set up by the supply current, whether single or polyphase, flowing in the windings of the stator or fixed portion of the motor. It is, however, only in single-phase types that after reaching full speed the rotating field (produced only during the starting-up period) is changed by switching to a simple alternating, or reversing, or pulsating field.

The speed attained at the end of the starting period with no pulley load is called "full" or "synchronous" speed, but in all induction motors the speed of the rotor decreases as the load increases.

If ( $f$ ) = the periodicity of the supply in cycles per sec.,

( $n$ ) = the speed of the rotor in revs. per sec.,

( $p$ ) = the number of pairs of poles in the stator,

then synchronous or full speed is the speed of the rotating field =  $\frac{f}{p}$  revs. per sec., while the difference between the speeds

of the field and rotor, called the "slip" =  $\frac{f}{p} - n = \frac{f - np}{p}$  revs.

per sec., and  $\left( \left( \frac{f - np}{p} \right) \div \frac{f}{p} \right) \times 100 = \left( \frac{f - np}{f} \right) 100$  = the slip in percentage of full speed, which varies from about two or three in large motors to as much as twelve in very small ones. We therefore see that the slip equals the periodicity of the rotor currents.

**Measurement of Slip.**—The last-named fact is made use of in the following method of measuring slip, but is applicable only in the case of induction motors with slip-ring rotors. Connect preferably a moving-coil permanent magnet D.C. ammeter in one

of the leads between rotor and starter, then since such an instrument indicates for currents in one direction only, the number of impulses given to, or kicks ( $K$ ) of, the pointer per min. in the same direction will directly equal the number of complete cycles per min. of the induced slow-period rotor currents—in other words the slip. If ( $f$ ) = periodicity of the supply to the stator, then the percentage slip =  $\frac{K}{60 \times f} \times 100$ .

Thus, if  $K = 120$  kicks per min., the slip =  $\frac{120}{60 \times 50} \times 100 = 4\%$  with a 50 ~ per sec. supply.

If a dead-beat moving soft iron needle A.C. ammeter is used, the number of kicks per min. would be doubled, for the same value of  $f$  and slip, and would, even if the ammeter was sufficiently dead beat to indicate with such rapidity, be impossible to count. With even a very dead-beat moving coil D.C. ammeter, a 5 or 6% slip is about the maximum measurable by this method. A slight variation of the above method consists in counting the oscillations of a light pivoted compass needle placed above or below one of the leads between rotor and starter, the lead having a direction N. and S. so that the needle lies parallel to it when no current is flowing. The slip is then obtainable as before.

The above are direct methods of measuring slip, but if a long-range accurate tachometer is available, the slip can be obtained usually with sufficient accuracy by reading the rotor speed ( $n_1$ ) running light, and ( $n_2$ ) at any load when the slip is given by  $\frac{n_1 - n_2}{n_1} \times 100\%$ .

**Determination of Slip by Calculation.**—If an induction motor has a three-phase wound rotor and both the rotor current ( $I_2$ ) and resistance ( $R_2$ ) per phase in each case are known, the slip ( $S$ ) in cycles per sec., or in percentage of the supply frequency ( $f_s$ ), or in revs. per min. or per sec., can be calculated for the corresponding load as follows—

If  $f_s$  = frequency of the rotor currents,

$W_2$  = mechanical output from the rotor of the motor (in watts),

$p$  = number of pairs of stator poles,

$W_1$  = power (in watts) transmitted electro-magnetically by the rotating field in the stator to the rotor,

$w$  = power (in watts) lost in the rotor  $= 3A_2^2 R_2$  approximately.

$$\text{Then torque} \propto \frac{2\pi f_2}{p} = W_1$$

$$\text{and torque} \propto \frac{2\pi f_1}{p} = W_2 + w (= 3E_1 A_1 \cos \phi \text{ for a 3-phase stator supply})$$

$$\therefore \frac{f_1}{f_2} = \frac{W_1}{W_2} = \frac{W_2 + w}{W_2}$$

and by a well-known rule in proportion we therefore have

$$\frac{f_1}{f_1 - f_2} = \frac{W_1}{W_1 - W_2} = \frac{W_1}{w} = \frac{W_2 + w}{w}$$

where  $W_1 - W_2 = w$

$$\therefore \text{the slip} = \frac{f_1 - f_2}{f_1} = \frac{w}{w + w} = \frac{3A_2^2 R_2}{W_2 + 3A_2^2 R_2}$$

### Determination of Frequency, Slip, and Speed (Stroboscopic Method).

**Introduction.**—Although the measurement of such quantities as those mentioned above—by this method—is by no means common, it probably only needs the advantages and accuracy of the method to be realized in order to bring it into much more general use.

**Measurement of Frequency and Slip.**—The phenomenon and principles of stroboscopy can be applied in the measurement of either the frequency of an alternating current supply from an alternator, or the slip of an induction motor, as follows: A black disc having white radial lines is fixed concentrically on the shaft of an A.C. motor run from the supply, and is illuminated by an A.C. arc lamp fed from the same supply. Now the illumination from the lamp will vary periodically and flicker with the supply frequency, and when the speed of the stroboscopic disc corresponds with this supply frequency, i.e. when the angular velocities of the two are equal, the white lines will always be illuminated in the same place and appear to be at rest. If the

speed of the disc is greater than that corresponding to the frequency of supply, the white lines will appear to slowly rotate in the *same* direction as the disc; whereas if the speed has a smaller value, the lines will appear to rotate in the *opposite* direction. The last condition will obtain with an induction motor, and if the number of white lines equals the number of pairs of stator poles, they will rotate in the opposite direction to that of the disc with the same number of revolutions per min. as those lost by the motor, i.e. as the slips.

For example: the rotating field in a 2-pole stator on a 50 ~ supply will make one revolution in the periodic time of the current, or will rotate with a speed of  $50 \times 60 = 3000$  revs. per min. If the slip between rotor and field is 5% ( $= 5 \times 30 = 150$  revs. per min.), a single white line on the black disc will appear to rotate backwards at a speed of 150 revs. per min., and will also make one complete revolution in the periodic time of the current.

With a 4-pole motor and the same slip and supply frequency, the speed of the rotating field equals 1500 revs. per min., slip equals 75 revs. per min., and each of the two white lines will appear to rotate at 75 revs. per min., which can be counted against time, and the slip thereby at once obtained. Sectors, alternately white and black, can be painted on the disc or even the pulley, and used instead of the black disc with radial white lines if so desired.

**Measurement of the Resistance of Single and Polyphase Windings.**—This is usually effected by the ammeter-voltmeter method with direct current (see p. 86) applied to a single phase-winding in the case of a single-phase generator or motor, and to each of the phase-windings separately of 2-phase machines.

Thus, if  $r$  equals resistance of each phase-winding, we see that the total copper loss in a single phase machine equals  $I^2 r$ ; and in a 2-phase machine equals  $I_1^2 r_1 + I_2^2 r_2$ ; or if in the latter case the resistances of the two windings are equal as they should be, and usually are, we have  $r_1 = r_2 = r$ , and if  $I_1 = I_2$  then the total copper loss  $W_c = I^2 \times 2r$ , where  $I$  is the current in either phase, and  $(2r)$  the so-called *equivalent* resistance of the machine.

In 3-phase windings, the resistance between any two terminals

is, with star connection, that of 2 phase-windings in *series* (as seen from Fig. 143 *a*), and therefore  $= 2r$ ; while with mesh connection (Fig. 143 *b*) we see that between any two terminals there are two circuits in *parallel*, composed of 1 phase-winding in parallel with the other 2 phase-windings in series, or ( $r$ ) in parallel with ( $2r$ ), i.e. a terminal resistance of

$$\frac{1}{r} + \frac{1}{2r} = \frac{1}{\frac{2}{3}r} = \frac{3}{2r}.$$

Now, if without troubling to trace the connections in order to see whether they are star or mesh, the resistance between the three pairs of phase-terminals are measured and added together, the sum  $\div 2$  will equal the *equivalent* resistance of the whole stator or rotor windings, and the total copper loss in the stator or rotor  $= (\text{line-current})^2 \times \text{equivalent resistance}$ .

### (97) No-Load "Open Circuit" Test of an Induction Motor on a varying Voltage, constant Normal Frequency Supply. (Rotor running Light at No Load.)

**Introduction.**—Under these conditions the motor will run at its maximum possible speed, namely that corresponding almost, but not quite, to true synchronism, and therefore with an almost zero slip—the small difference being necessary for overcoming the small losses due to windage, mechanical and magnetic frictions, and copper loss due to the no-load running current. The test can be operated, of course, on single, two, or three phase motors, but we shall assume the use of a three-phase motor here on account of the connections being slightly more complex.

Such a motor may have either a *squirrel-cage* (short circuited) rotor or a *wound* rotor with slip rings. If the former, it may be started up from full voltage mains either by a *star-delta* switch or through an auto-transformer or sectioned choker, depending on its size. If it has a wound rotor, the starting rheostat connected to this is put to "full in" and the stator then switched directly to the supply. The starter is then gradually cut out to short circuit as the speed increases. If

now, with the motor running at full speed, normal voltage, and frequency, the voltage is gradually decreased, the speed will remain practically constant until the lower voltages are reached, when it will fall off rapidly.

Both the stator and rotor current will also decrease gradually, the former owing to a decrease in magnetizing and core-loss current producing the stator flux and depending on the voltage, the latter in an inverse proportion to the strength of the rotating field and voltage.

As the voltage falls the idle or magnetizing component of the current will also decrease, while the energy component overcoming frictions will remain much the same in value, hence

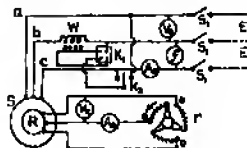


FIG. 28.

the ratio of idle to energy current will decrease and the power factor will in consequence rise.

If  $V_s$  = normal voltage per phase on the stator and  $V_r$  = the corresponding maximum voltage per phase of the rotor indicated when this is turned through a pole pitch with slip rings open-circuited. Then  $\frac{V_r}{V_s}$  is called the ratio of trans-

formation, which is not equal to the ratio of the stator and rotor currents owing to the magnetizing current of the stator. The induced E.M.F. in the rotor circuits varies directly as the slip, and has a frequency  $f_s$  = the slip. Thus the reactance of the rotor circuits ( $= 2\pi L_R f_s$ ) bears a constant ratio to the slip.

As the rotor current is not usually measured, the ratio of transformation enables it, and also the most suitable starting resistance, to be calculated, knowing the stator current at any load.

**Apparatus.**—Source  $E$  of three-phase alternating current, preferably a motor-driven alternator, the speed and field of

which are each variable between wide limits; three-phase switch  $K_1$ ; voltmeters  $V_s, V_R$ ; ammeters  $A_s, A_R$ ; frequency meter  $f$ ; wattmeter  $W$ ; reversing key  $K_1$  (p. 585); and two-way key  $K_2$  (p. 587) for fine-wire circuit of  $W$ ; three-phase induction motor, of which ( $S$ ) is the stator and ( $R$ ) the rotor and ( $r$ ) the starter.

**Note.**—By the use of only one wattmeter, with its pressure-coil connected through  $K_2$  to the remaining two mains in rapid succession, we assume the motor to be electro-magnetically balanced, or equally loaded, in the three phases (see p. 389). On no load, such is usually the case, for the current  $A_s$  is small, and therefore any inequality in the ampere turns, resistance, or reactance of the windings is nearly negligible in effect compared with what it would be on load. With phase-windings *unequally* loaded or balanced, two wattmeters must be used to obtain the true power absorbed (see p. 392).

The ammeter  $A_R$  in the rotor circuit should be very dead beat and of the moving needle type, and should be of low resistance so as not to throw out the balance of the rotor currents. If the rotor  $R$  is of the squirrel-cage type,  $V_R, A_R$  and  $r$  cannot be used.

**Observations.**—(1) Connect up as in Fig. 98, levelling and adjusting to zero, such instruments as need it. On starting any machine always see that its oiling arrangements are working properly before doing anything else.

(2) With  $R$  running light at no load, adjust the voltage  $V_s$  and frequency  $f$  of the supply  $E$  to the normal values for the motor, and note the readings of all the instruments under this supply condition, and also (with the same frequency kept constant) for a series of values of  $V_s$  (by field regulation) decreasing by about equal amounts to the point where the speed *begins to decrease*, and from this point by *smaller and more gradual* decrements of  $V_s$  until the speed decreases too rapidly to read.

**Note.**—After the speed begins to fall, sudden changes in  $V_s$  must be avoided, while the simultaneous readings of all the instruments must be taken rapidly.

$W$  must be read, first with its volt coil across ( $ab$ ) and then with it across ( $bc$ ) at each voltage  $V_s$ , by using the key  $K_2$ . Further, in some cases (not all), this change of connection will be accompanied by a reversal of direction of the deflection of  $W$  depending on the magnitude of the power factor. The re-





wholly consist of copper loss  $\propto$  to the square of the current. The only remaining source of loss is that due to hysteresis and eddy currents in the iron which will be small, owing to the low induction density reached with even the maximum voltage it is possible to use in this test. Further, it will be noticed, from a reference to test No. 137, that the motor approximates to a static transformer with a stator primary and rotor secondary under the conditions for maximum magnetic leakage which the stator windings maintain in the air gap between stator and rotor.

Under stationary conditions the ratio of stator to rotor current is practically a constant and approximates to the ratio of transformation of the motor. Under running conditions the ratio of currents departs from constancy, due to the no-load current taken by the motor at normal voltage, and no longer approximates to the ratio of transformation.

**Apparatus.**—That indicated for the preceding test (p. 265), but without  $K_1 A_2$ , an additional wattmeter now being used with its current coil in main  $a$  or  $c$  (Fig. 98), one end of each of the volt circuits of the two wattmeters, to be denoted by  $w_1$  and  $w_2$ , being connected to the third main as indicated in Fig. 143c. The reason for now using two wattmeters is that the heavier stator currents to be used in this test, which will depend mostly on the resistances of the windings, will show up any slight want of symmetry, and may (or may not) result in the unequal current loading of the three phases—a condition necessitating the use of two wattmeters (p. 392).  $A_s$ ,  $A_R$ ,  $w_1$  and  $w_2$  must also now be capable of taking the heavier currents used in the present test.

**Observations.**—(1) Connect up as in Fig. 98, levelling and adjusting to zero such instruments as need it. See that the lubricating arrangements of the supply set are working properly.

(2) With the rotor *R* short-circuited and prevented from rotating and the supply frequency ( $f$ ) constant at normal value, take the readings of all the instruments at each of a series of supply voltages  $V_s$ , increasing from zero to a value which will produce a stator current  $A_s$  of, say, 50% in excess of that of full load, and tabulate as for the last test (p. 267).

(3) Plot curves, having values of  $V_s$  as abscissae, with values of  $W$ ,  $A_s$ ,  $A_R$  and  $\cos \phi$  respectively, as ordinates. Also curves between  $A_s$  as ordinates, with  $A_R$  as abscissae, for this test, and from the readings of the last test No. 97 on the same curve-sheet for comparison.

**Inferences.**—From a careful study of the curves state clearly all that can be deduced from the test.

### (99) Efficiency and B.H.P. of Single Phase Alternating Current Electro-Motors.

**Introduction.**—The somewhat rapid development of the distribution of electrical energy by single phase alternating currents in recent years has brought with it the introduction of single phase alternating current motors, of which, up to comparatively recently, there has been no practical commercial instance. Now, however, there are several forms, but none of them are able to compete with the direct current motor in the matter of efficiency and powers of starting under load with the amount of electrical power absorbed in doing so. There are two classes of alternating single-phase motors, known as the *Synchronous* and *Asynchronous* types. The former cannot start themselves but have to be run up, by a separate source of power, into synchronism with the periodicity of the supply current; then, on being switched into circuit, they run perfectly synchronously with the generators, i. e. at constant speed, for wide variations of load from 0 to considerably over full load, and are of course separately excited. The latter class are self-exciting and self-starting (on very small loads) by using suitable means, but are non-synchronous, and the difference between the speeds of rotation of the magnetic field and the rotating armature is called the "Magnetic Slip" or "*Slip*" simply. This generally only amounts to a small percentage at full load.

The self-starting property is obtained by producing a rotatory magnetic field at starting, caused by diphasing the current in two separate circuits by means of the suitable use of either self-induction or capacity, one circuit being cut out when the motor gets up speed.

The fixed portion of the motor (i. e. field magnets) through the

winding of which the supply current flows is usually termed the "Stator." The rotating portion (i. e. the armature) is termed the "Rotor," and usually consists of short-circuited conductors carried on a well-laminated drum. There is no electric connection in most cases to the rotor, or between rotor and stator. It will also often be found that the best efficiency is not at normal full load, which is analogous to the series wound direct current motor in this respect. Speaking broadly, it may be said that single-phase motors should be self-starting, and this on a current certainly not exceeding that taken at full load. The *power factor* should be high.

A motor built for a given periodicity will not give as a rule its full power when supplied with a current of a much higher periodicity, while it will take too much current with a lower periodicity.

The efficiency of any motor = the total power given out  $\div$  the total "mean power" absorbed, both being reckoned in equivalent units. In the present and similar tests the true mean input cannot be obtained by the product of the amperes and volts, as in the case of direct current motors, owing to the "phase difference" between the current and pressure, but must be obtained by means of a non-inductive Wattmeter. The output, or B.H.P., is obtained by an absorption dynamometer, which is a modified form of Prony brake. Such brakes waste, in heat, all the power developed by the motor from friction, but at the same time give a measure of this power. No lubricant is usually needed, but a little black lead may be applied to the pulley if the brake is jerky.

**Apparatus.**—Alternating current motor *M* to be tested; brake complete with weights; non-inductive Wattmeter *W*; alternating current ammeter *A* and voltmeter *V*; switch *S*; rheostat *R* (p. 597); tachometer; source of alternating current *E*, preferably one that can be varied.

**Tests.**—(1) Connect up as indicated, and adjust the pointers of all the instruments to zero, levelling such as need it. See that all lubricators in use feed slowly, and that the resistance switch (*S*) is open.

(2) Adjust the speed and excitation of the alternator so as to give the normal voltage and frequency required for *M*, and remove the brake.

(3) Make *R* a maximum; i. e. in the present case put resistance

switch  $S$  to *start*, and when the motor has got up speed throw  $S$  over from *start* to *full*, then, when the speed has become steady, note it and the readings of  $A$ ,  $V$ , and  $W$ .

(4) Place the brake in position, and with no weight in the pan, again note the motor speed and readings of  $A$ ,  $V$ , and  $W$ .

(5) Repeat 4 for about ten loads, rising by about equal increments of weight to the maximum, the voltage and frequency being kept constant.

(6) Repeat 4 and 5 for a higher and lower frequency than the normal.

(7) Determine the power required to just start  $M$  by removing the brake, turning  $S$  to *start*, and adjusting the speed of the alternator to give normal frequency (to be kept constant).

(8) Carefully and gradually raise the voltage (at constant speed) by means of the excitation until  $M$  just starts, then instantly note the readings of  $A$ ,  $V$ , and  $W$ . Repeat this three or four times and take the mean.

(9) Repeat 7 and 8 for about five different frequencies, rising by about  $\frac{1}{2}$  increments to about 20% above normal.

(10) Determine the relation between the speed of  $M$  and frequency of supply by removing the brake, and when the motor has got up speed, turning the Switch ( $S$ ) to "full." Then for constant normal voltage note the speed of  $M$  and readings of  $A$ ,  $V$ , and  $W$  for about ten different frequencies, rising up to about 20% above normal.

(11) Determine the effect of variation of voltage at constant normal periodicity with the motor running light by altering  $R$ , and noting the speed and readings of all the instruments. Tabulate all your results as shown.

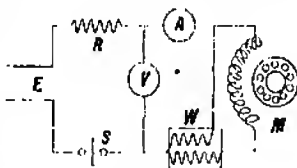


FIG. 99.

Name . . .

Date . . .

Motor: No. . . . Type . . . . Made by . . . . Effective Diam. of Pulley and Load  $d =$  . . . ft.  
 Normal B.H.P. = . . . at . . . volts and . . . revs. per min., and frequency = . . . per sec.  
 Alterations per revolution of Dynamo  $K =$  . . .

Speed in revs. per min., of	Motor No.	Frequency per sec. $\times \frac{60}{\pi}$	Volts $V$	Amps. $A$	Power Absorbed, Watts	Weight in Fan w. lbs.	Lesser weight or balance reading w. lbs.	Net Weight in brake ( $W - w$ ) lbs.	B.H.P. developed $H_d = \frac{W(R - w)}{33000}$	Power Factor $\cos \theta = \frac{W}{VI}$	Angle $\theta$	Efficiency $\frac{H_d \times 100}{VI}$	Slip.
					Apparatus Watts $W_a$								
					True H.P. $H_t = \frac{W_a}{746}$								

**Note.**—The nett weight on brake = (weight of scale pan and weights) — reading of spring balance.

(12) In experiments 1-6 plot curves having values of (a) power factor, (b) efficiency, (c) true power absorbed respectively as ordinates, and B.H.P. developed as abscissas, for each frequency.

(13) In experiments 7-10 plot curves having (d) true power required to start, (e) speed of motor, as ordinates and frequency as abscissae, in each case.

**Inferences.**—What can you deduce from your experimental results? Taking the cost of electrical energy for power purposes at 2d. per B.T.U., find the cost per B.H.P. per hour, and also when  $M$  is running on no load at normal voltage and frequency.

### (100) Efficiency-Load Test of a Polyphase Induction Motor. (Absorption - Brake Method.)

**Introduction.**—The efficiency of any electro-motor

$$= \frac{\text{B.H.P. developed}}{\text{E.H.P. absorbed}} = \frac{\text{B.H.P.}}{\text{B.H.P.} + \text{internal losses}}$$

The internal losses in an induction motor comprise (1) copper losses in stator and rotor windings, (2) iron losses (hysteresis and eddy currents) in stator and rotor cores, (3) mechanical friction due to windage, journals, and brushes, if it possesses a slip-ring rotor.

If  $A_s$  and  $r_s$  = the current and resistance, respectively, per phase of stator winding and  $A_r$  and  $r_r$  = the current and

resistance, respectively, per phase of rotor winding; then, if this latter is of a three-phase type, the stator copper losses are—

$A_{sN}^2 R_s$  for single-phase;  $2A_{sN}^2 R_s$  for two-phase; and  $3A_{sN}^2 R_s$  for three-phase induction motors, while the rotor copper loss is  $3A_R^2 R_R$ .

For a given iron core, we have seen (p. 354) that the expression for the iron losses contains two variables only, namely, the frequency and the induction density  $\propto$  to flux, and dependent solely on the supply voltage and number of stator turns. Hence the iron loss is independent of load. Further, since the frequency of the rotor currents and consequently of the flux in the rotor core equals the slip, which is only some 5% of the speed of the stator field, it follows that the iron loss in the rotor core will be small compared with that in the stator core and the other losses, and will increase slightly with speed. The friction losses being  $\propto$  to speed, will be sensibly constant at all loads in an induction motor, since the speed of such a motor has a variation of some 5% only. It will therefore be at once realized that the copper losses (increasing as the square of the current) are mostly responsible for the rapid increase of the total internal loss as the load increases.

The supply current to the stator of an induction motor is composed of two components—

(a) One which may be termed the no-load or magnetizing component, producing the rotating magnetic field, and which is not only in quadrature with the supply voltage but nearly constant at all loads.

(Owing to the air-gap between stator and rotor-cores, the ampere turns of excitation, and hence the magnetizing component necessary to produce a given flux, is much higher, and the power factor much lower, than if the magnetic circuit was a closed one, and therefore an induction motor takes a considerable no-load current which may be from a quarter to one-third of full-load current. The smaller the air-gap the smaller this current, the greater the power factor and output of the motor for a given size. For this reason the air-gap of such motors is reduced to a mere clearance for rotation.)

(b) The other, which may be called the load-component, out

of phase with the voltage, but producing a field in the stator equal and opposite to that produced by the rotor currents in the stator, and hence balancing the demagnetizing effect of the rotor-induced currents on the stator field.

This load component increases directly with the B.H.P. output of the motor and  $= I_a \times \frac{\text{turns on rotor}}{\text{turns on stator}}$ .

Thus it will be seen that for the rotating field to have a constant strength, the stator current taken at no load will just suffice to produce this requisite field strength and provide for the iron and friction losses. As the load increases, the increase in the rotor ampere turns is balanced by an equal and opposite increase in stator ampere turns, and we have the following relation, viz. that the

$$\begin{aligned} &\text{Total stator amp. turns} \\ &= \text{total rotor amp. turns} + \text{no-load amp. turns,} \\ \text{or Total stator current} \\ &= (\text{rotor current} \div \text{ratio of transformation}) + \text{no-load current,} \end{aligned}$$

the line above denoting that the sum is vectorial and not algebraical.

The total power given out, i.e. the B.H.P., can be measured either by means of an absorption dynamometer brake in the manner already clearly defined in the previous tests, or by making the motor to be tested drive a direct current dynamo, the *commercial efficiency* of which is accurately known at various loads. This method should be adopted whenever possible, as it has the advantage, when carried out properly, of being more accurate than the ordinary brake methods. The method consists in suitably driving the dynamo from the motor to be tested either by means of a *thin* supple (pliable) belt or by the direct coupling of their shafts (placed accurately in alignment), through a flexible coupling or helical spring sufficiently strong for the purpose, thus avoiding the difficulty of getting their shafts *exactly* in true alignment. The belt arrangement also obviates the same difficulty, but it must be very pliable, otherwise errors will be introduced due to the extra power absorbed by the slipping and bending of this belt round the pulleys.

Thus measuring the electrical power developed by the dynamo which is at once given by the current  $\times$  voltage, and knowing its commercial efficiency  $e$ , the B.H.P. of the motor can easily

be calculated and  $= \frac{\text{D.C. output}}{746} \div e$ . Further, if  $n$  = the speed in revs. per min., the torque  $T$  of the motor is given by the relation  $T = \frac{\text{B.H.P.} \times 33000}{2\pi n}$  lb. ft.

In all cases the efficiency of any motor = total power given out at its pulley  $\div$  total power absorbed, both being reckoned in equivalent units. A multiphase alternating current motor is *self-exciting, self-starting*, but *asynchronous* as regards speed and the periodicity of the supply. The starting torque can be made equal to that of the best direct current motor without an excessive percentage over load in the current taken.

They can be wound to run direct on 5000 volt circuits and

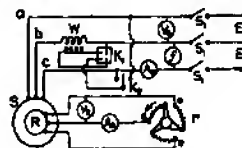


FIG. 100.

over without much fear of the insulation breaking down, and their great advantage, except in the larger sizes, lies in the fact that there are no rubbing contacts of any kind to get out of order, and consequently there is no sparking. In the present case we will assume that the motor to be tested is of the three-phase type, as perhaps the measurements of input are not so obvious as in the two-phase system.

**Apparatus.**—Source of three-phase alternating current  $E$ ; three-phase motor  $SR$  to be tested either coupled mechanically to a direct current dynamo  $D$  of known commercial efficiency, or fitted with a Peony brake, p. 634; Wattmeter  $W$ ; alternating current ammeters  $A_1, A_2$  and voltmeters  $V_1, V_2$ ; triple pole switch  $S_1, S_2, S_3$ ; tachometer; and if a coupled dynamo load is used, direct current ammeter  $A$  and voltmeter  $V$ ; rheostat  $R$  (p. 606); switch  $S$ .

**Note.**—For a detailed description of power measurements in multiphase circuits, see pp. 388–400.

**Observations.**—(1) Connect up as in Fig. 100, and adjust all the instruments to zero, levelling such as require it. See that





(7) Plot the following curves from observations 3 and 4 for each speed having efficiency, power factor, slip, speed, current, and intake Watts as ordinates and B.H.P. as abscissae, also curves having Torque as abscissae with  $A_1$ ,  $A_2$  and slip as ordinates.

And from observations 5 and 6, curves between voltage  $V_s$  and supply frequency as ordinates with speed of the motor as abscissae in each case.

**Inferences.**—State very clearly all the inferences which can be drawn from your experimental results, and point out their bearing on electrical driving by multiphase current motors.

### (101) Determination of the performance of an Induction Motor at all loads without loading it at all. (Heyland's Method.)

**Introduction.**—It sometimes happens to be inconvenient and even impossible to brake, or otherwise absorb the B.H.P. of large induction motors, and in other cases to supply the large amount of electrical power required by them at full load from a generating plant which may be already running nearly at full load. The difficulty is met fortunately in such cases by the following method entailing the construction of the well-known "*Heyland Diagram*" from very simple "*no load and short circuit*" readings on the motor. The intake current and power, the output, the power factor, and the slip, etc., and hence efficiency, can then be deduced for all B.H.P.s and a complete set of curves drawn showing the performance of the motor. The temperature rise at any load cannot however be obtained with this method, and the best and most economical way of determining it is to let the motor drive a generator which is capable of absorbing the required B.H.P. and simultaneously return the output of this generator to the motor supply. Thus in running a 6 hours' temperature test on, say, a 500 B.H.P. motor having an efficiency of 95%, the power wasted would only

be some 10% or about 50 H.P. as against over 500 H.P. if the output of the generator had been taken up in rheostats.

**Apparatus.**—Three-phase induction motor  $M$  with phases equally balanced (presumably) complete with starter. A tachometer; a voltmeter; an ammeter reading up to at least full load intake amperes, and a source of supply  $SS$  at the normal voltage and frequency for which the motor is built and capable of reduction to about  $\frac{1}{2}$  full normal voltage at full normal frequency, as before, together with—

For motors with *mesh-connected stator*—2 similar wattmeters having a capacity of about  $\frac{1}{3}$  of the full load output of the motor.

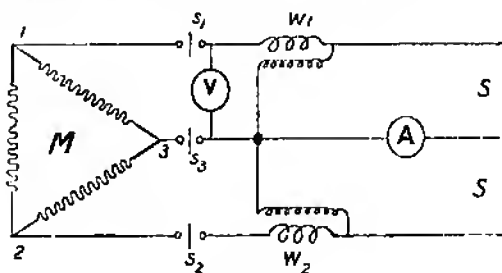


FIG. 101.

For motors with well-balanced *star-connected stator*—1 wattmeter having a capacity of about  $\frac{1}{3}$  of the full-load output of the motor.

The ohmic resistance of a complete stator phase (and of a rotor phase for reference later, if needed) will be required, and can be obtained from a separate measurement with a high-reading ammeter and low-reading voltmeter, by the fall of potential method (*vide* p. 84).

**Observations.**—(1) Connect up as in Fig. 101 if the motor stator is mesh connected or if the stator is star connected but not well balanced, and adjust the pointers of those instruments which require it, to zero. The terminals of the stator of the motor  $M$  are 1, 2 and 3, whether it is star or mesh connected.

(2) Close the switch  $S_1$ ,  $S_2$ ,  $S_3$  and start up  $M$ , finally short-

circuiting the starter. Then with the supply at normal voltage and frequency note the speed of  $M$  on the tachometer and the readings of all the instruments, the motor running quite light and at "no load."

N.B.—If the power factor of the system is low, one of the wattmeters will read negatively. Reverse the connections to its shunt coil and take the reading which must be considered —" and subtracted from the reading of the other wattmeter to get the total true power.

(3) Open  $S_1, S_2, S_3$  and when the motor comes to rest, clamp the shaft in any convenient way to prevent it rotating, and place the starter at short-circuit. Now apply any convenient lower voltage, say,  $\frac{1}{2}$  to  $\frac{1}{4}$  of the normal value at full normal frequency, and again read all the instruments as in Test 2 above and switch off and open the starter.

Note.—A lower voltage has to be used in this test for the larger-sized motors, because the normal voltage would cause dangerously large currents to flow which would probably damage the stator winding in even their brief application. The true static current will now be the observed current  $\times$  by the ratio of the two voltages, while the corresponding static watts will be those observed  $\times$  by the square of this ratio (see table). The reason for this is that the static watts are nearly all copper loss and hence  $\propto$  to (current)<sup>2</sup>.

(4) Measure in a convenient manner (pp. 84 and 263) the resistance  $R_s$  between any two terminals of the stator and rotor, preferably while warm. Then the resistance of each complete stator phase (star connections)  $r_s = \frac{R_s}{2}$ ; and for (mesh connections)  $r_s = \frac{2}{3} R_s$ . Also in the case of a slip ring rotor obtain the ratio of transformation given by the ratio of any stator voltage to the corresponding rotor voltage with rings open-circuited and rotor in the position giving max. volts.

Record your results as follows—



**Construction of Heyland Diagram.**—This will be understood more easily by working it out from tests recently made by the author on a 360 B.H.P. 500 volt three-phase induction motor, running at a speed of 300 revs. per min. with a normal frequency = 50 ~ per sec. The stator windings were star connected, the rotor windings being also star connected, and led out to three slip rings which were connected to a starting resistance. The method of procedure with this motor was as follows—

With an ammeter in one line and a wattmeter connected between the neutral point and one terminal of the motor so as to measure the true watts absorbed by one phase (see Fig. 151, p. 396), the following measurements were made—

**Motor running light at normal speed, frequency, and voltage with rotor short circuited.**—Wattmeter reading = 3600 watts per phase =  $\left(\frac{w}{3}\right)$ .

Line current ( $A_L$ ) = 142 amperes.

Resistance of each phase of stator (cold)  $r_s$  = 0.0122 ohm., or by calculation about 0.013 ohm. (hot) on the assumption of a maximum temperature rise of 70° F. above that of the air.

Resistance of each phase of rotor (cold)  $r_r$  = 0.0051 ohm.

Ratio of transformation in rotor 500:325.

Bearing in mind always that the diagram is constructed with reference to one phase of the motor, and not the motor as a whole. Further that in testing motors with mesh connected stators it would be the total power absorbed that would be measured by the two line wattmeter method (Fig. 101, p. 276) instead of that per phase.

Hence the power factor of any phase, whether in star- or mesh-connected stators, can be calculated best from the general relation

$$\cos. \theta_2 = \frac{\sqrt{3}w_p}{3A_L V},$$

where  $w_p$  = total power in watts absorbed by motor running light with a line current  $A_L$  and line voltage  $V$ . The numeral 3 reduces  $w_p$  to watts per phase, and  $\sqrt{3}$  reduces the line voltage  $V$  or line amperes  $A_L$  to the corresponding quantities per phase in the case of star- or mesh-connected stators respectively. Thus in the present case

$$\cos. \theta_2 = \frac{\sqrt{3}w_2}{3A_2V} = \frac{\sqrt{3} \cdot 10800}{3 \cdot 142 \cdot 500} = 0.0878$$

or  $\theta_2 = 85^\circ$ .

**Motor at standstill with rotor short circuited and stator supplied at normal frequency.**—With these conditions we require the line current that would flow, and also the true watts absorbed, at normal line voltage. As, however, a line voltage as great as the normal value would, in most motors, produce an abnormal current that would be inconvenient to measure and liable to damage the windings, a smaller voltage sufficient to give a convenient line current is applied. Thus in the present case the line current  $A_L' = 104$  amps.

„ pressure  $V_s = 127$  volts.

Wattmeter reading  $\left(\frac{w_s'}{3}\right) = 8000$  watts per phase.

From which we calculate the following static standstill values—

Line current

$$A_L = \frac{\text{normal volts}}{\text{applied volts}} \times 404 = \frac{500}{127} \times 404 = 1591 \text{ amps.}$$

Total watts absorbed

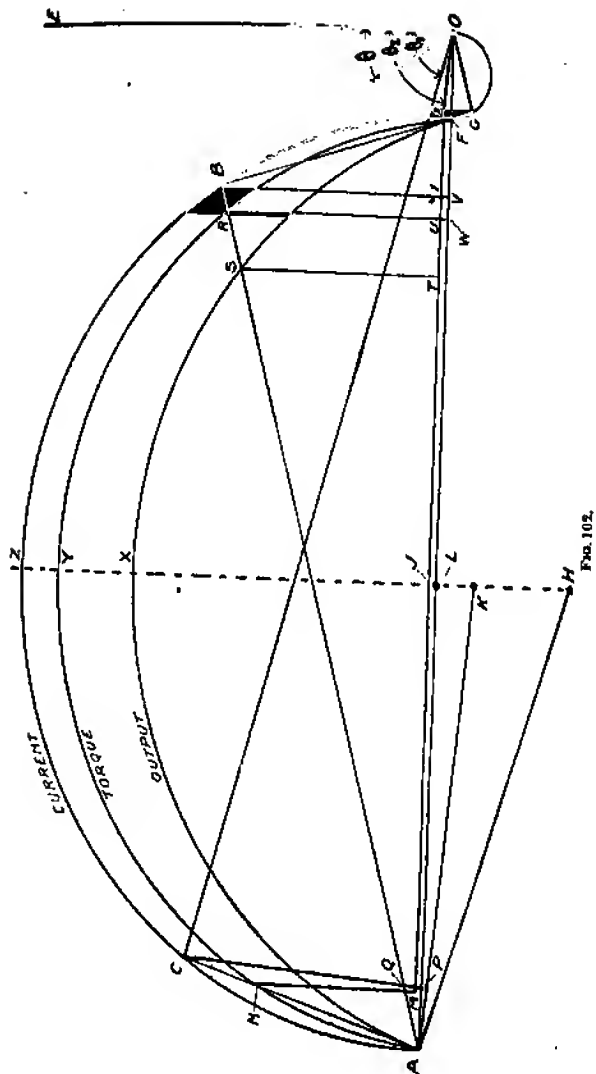
$$w_s = \left(\frac{500}{127}\right)^2 \times (3 \times 8000) = 372,000 \text{ watts,}$$

$$\text{whence } \cos. \theta_1 = \frac{\sqrt{3}w_1}{3A_1V} = \frac{\sqrt{3} \cdot 372000}{3 \cdot 1591 \cdot 500} = 0.2701$$

or  $\theta_1 = 74.3^\circ$ .

**Current Circle.**—Referring to Fig. 102, draw two lines  $OE$  giving the phase of the supply volts and  $OA$  perpendicular to one another, and from the point  $O$ , as origin, set off a straight line  $OC$  (= current which would be taken by the stator if directly across normal voltage), making an angle  $\theta_1$  of  $74.3^\circ$  with  $OE$  and another line  $OD$  (= no-load current) making an angle  $\theta_2$  of  $85^\circ$  with  $OE$ . Now choose a convenient linear scale of current, e.g. in the present case, 100 amps. = 1 cm., and thus make

$$OC = 1591 \text{ amps.} = \frac{1591}{100} = 15.91 \text{ cms. long,}$$



**FD-102,**



and make  $OD = 142$  „  $= \frac{142}{100} = 1.42$  cms. long.

Then with a centre  $L$  (on  $OA$ ) draw a semi-circle  $ACD$  through the points  $C$  and  $D$ , and cutting  $OA$  in  $A$  and  $F$ , thus determining the point  $A$ . From  $D$  draw  $DF$  = energy component of no-load current perpendicular to  $OA$  and cutting it in  $F$ , then  $DFO$  is the no-load triangle of currents  $OP$  = the no-load magnetizing current  $\cos \theta_1$  = the no-load power factor. Rotor current =  $FB \times$  ratio of transformation stator intake  $\propto BV$  and  $AXF$  is the current circle for the motor.

**Output Circle.**—Join  $CA$ , and from  $A$  draw  $AH$  perpendicular to  $AC$ , cutting the perpendicular  $HX$ , to  $OA$  through  $L$ , in the point  $H$ . With centre  $H$  draw the output semi-circle  $AXF$  through the points  $A$  and  $F$ . Since the angle  $CAH = 90^\circ$ , the line  $CA$  is a tangent to the output circle, the ordinate of which at  $A$  is zero, thus satisfying the condition of no output corresponding to this point and the point  $C$ , output of motor =  $ST$  which has a max. value =  $XI$ .

**Torque circle.**—The torque of an induction motor is proportional to the rotor flux ( $R_r$ )  $\times$  the rotor current ( $R_i$ ) and in fig. 102 the right-angled triangle  $ACO$  is a triangle of fluxes in which  $AC \propto R_r$ ;  $AO \propto$  stator flux ( $S_r$ ) which is also  $\propto$  applied voltage per phase and  $OC \propto$  leakage flux  $L_r$ . Consequently the actual rotor flux will be  $\propto AC$ —copper drop in stator resistance, and we proceed by first finding the voltage represented by  $AC$  when the volts per phase of stator are represented by  $AO$ . Thus—

$$\frac{\text{volts per stator phase}}{\text{volts represented by } AC} = \frac{\text{length of } AO}{\text{length of } AC} = \frac{16.7 \text{ cms.}}{4.55 \text{ cms.}}$$

whence—volts represented by

$$AC = \frac{AO}{AO} \times \text{volts per phase} = \frac{4.55(500)}{16.7(\sqrt{3})} = 78.66 \text{ volts.}$$

Now the copper drop for stator phase (for the short circuit current  $I_s = 1591$  amps.)

$$= A_s r_s = 1591 \times 0.013 = 20.68 \text{ volts.}$$

Therefore from the point  $C$  mark off along  $CA$  the length  $CN = 20.68$  volts, which is proportional to

$$\frac{A_s r_s}{78.66} \cdot AC = \frac{20.68 \times 4.55}{78.66} = 1.196 \text{ cms.}$$

Now find a centre  $K$  in  $ZH$ , such that a semi-circle  $ANVF$  described from it passes through the points  $ANF$ . This is the required torque circle. Since the rotor flux is represented by  $AN$ , the total torque is  $\propto AN \times CF$  which is  $\propto$  to the area of the right-angled  $\triangle ANF$  (the line  $NF$  not being shown in Fig. 102). But the base  $AF$  is constant. Hence the total torque is  $\propto$  to the altitude of the triangle. For example the total torque is  $\propto RV$  for the stator current  $OB$ . Again, in the no load triangle of currents  $ODF$ , the no load wattless magnetising current =  $OF$  lagging  $90^\circ$  in phase behind the E.M.F.  $OE$ , and having a load current component in phase with  $OE = FD$ . The resultant no load stator current as read off on the ammeter =  $OD$ . Hence, since useful torque = total torque - torque spent in overcoming internal frictions for the same stator current  $OB$ , we have useful torque  $\propto RV - UV \propto RU$ . Starting torque would be  $AM$  at the starting current  $OF$  and a power factor  $\cos \theta_1$ .

**Slip of the Motor.**—Since we know that the slip is directly  $\propto$  to the rotor current  $NF$ , and inversely  $\propto$  to the rotor flux  $AN$ , we see that it will have its maximum value at  $C$  and minimum value at  $D$ , for  $\frac{NF}{NA}$  (which is  $\propto$  to slip) has its maximum value unity at  $C$  when the motor is at standstill.

From  $C$  therefore draw  $CP$  perpendicular to  $AK$  cutting  $AO$  in  $P$ . Then the slip  $\propto \frac{NF}{NA} \propto \frac{QP}{AP} \propto QP$ , since  $AP$  is constant and the triangles  $ABF$  and  $APQ$  are similar.

Now maximum slip corresponding to the point  $C$  and the motor at standstill is  $\propto CP$ , which scales 4.35 cms. and represents 100 % slip.

The slip at the output load  $ST$  when taking a stator current  $OB$  is  $\frac{\text{length } PQ}{\text{length } PC} \times 100 \% = \frac{0.3}{4.35} \times 100 = 6.9 \%$ .

Stator copper loss =  $(BV - EV)$  watts and rotor copper loss =  $(RU - SU)$  watts each to a scale of watts suitable for input  $BV$  and output  $ST$ ,  $BR$  and  $RS$  = ohm drop of volts in stator and rotor respectively to same scale as  $OA$  gives stator volts per phase.

**Application of Diagram.**—The diagram can now be employed for determining the performance of the motor at any load corresponding to any point such as  $B$  taken anywhere on the current curve  $AZF$ . Suppose that we choose the point  $B$  as being the point of contact of the tangent  $OB$  with the current circle  $AZF$ . Join  $AB$ , cutting  $CP$  in  $Q$ , the circle  $AXF$  in  $S$ , and  $AYF$  in  $R$ , and draw the perpendiculars  $ST$ ,  $RUV$ , and  $HW$ .

**Power Factor.**—For any given point on  $AZF$  the power factor is given by the cosine of the angle between the join of this point with  $O$  and the line  $OE$ . At  $B$  it has the maximum value possible, since  $OB$  is a tangent to the circle, namely

$$\cos \theta = \cos 32.6^\circ = .8406.$$

**Stator Current per phase** =  $OB$ , which is also the line current in the present case since the stator is star connected.

This scales 4.95 cms. corresponding to 495 amperes (since 100 amps. = 1 cm.).

**Total Apparent Watts absorbed** =  $\sqrt{3} \cdot V \cdot \text{line amps.} = \sqrt{3} \cdot 500 \cdot 495 = 428,600 \text{ watts.}$

**Total True Watts absorbed** =  $\sqrt{3} \cdot V \cdot (\text{component of } OB \text{ in phase with and parallel to } OE).$   
 $= \sqrt{3} \cdot V \cdot BY \text{ with star connections} = \sqrt{3} \cdot 500 \cdot 416 = 360,200 \text{ watts.}$

The same result is given by  $3(BI') \times \text{volts per phase.}$

**Stator copper loss** for this load =  $3 (r_s \times \text{component } FB^2 \text{ of stator current}) = 3 \cdot 0.013 \cdot (435)^2 = 7381 \text{ watts.}$

This loss is proportional to  $BR$  which = 0.43 cm., and the **Rotor copper loss** is  $\propto$  to  $RS$  which = 1.0 cm., and this loss therefore =  $\frac{1}{.43} \times 7381 = 17,165 \text{ watts.}$

**The total loss** in the motor at the load corresponding to the intake stator current  $OB = 10,800 + 7381 + 17,165 = 35,346 \text{ watts.}$

**The output** of the motor therefore =  $360,200 - 35,346 = 324,854 \text{ watts} = 436 \text{ B.H.P.}$

**The efficiency** of the motor therefore =  $\frac{324,854}{360,200} = 90.18 \%$  when giving 436 B.H.P. or 21 % overload with a power factor already found of 84 %.

The ordinate  $ST$  thus represents 436 B.H.P. or the scale of the ordinates of the output circle is  $\frac{436}{ST} = \frac{436}{3.65 \text{ cms.}} = 119.5$

B.H.P. per 1 cm., consequently the rated full load of the motor, namely 360 B.H.P., will be given by an ordinate such as  $ST$ , but only 3.014 cms. long.

The efficiency, power factor, and slip, etc., can now be worked out for this new full load point which gives another point, such as  $B$  on  $AZF$  nearer to  $F$  and a line such as  $AB$ , at a smaller angle to  $OA$ . Hence the performance at any load can be determined.

Further, if  $T$  = the torque in pound feet,  
and  $\omega$  = the angular velocity of the rotor =  $2\pi n$ ,  
where  $n$  = the revs. per min. of the rotor at a given B.H.P.,  
then  $\text{B.H.P.} = \frac{\omega T}{33,000} = \frac{2\pi n T}{33,000}$  or  $T = \frac{33,000 \text{ B.H.P.}}{2\pi n}$ .

Now since at  $B$  the B.H.P. = 436 and the slip = 5.9 %  $\therefore n = 300 \times 93.1$   
 $\frac{100}{100} = 279 \text{ r.p.m.} \therefore T = \frac{33,000 \times 436}{2\pi \cdot 279} = 8210 \text{ lb. ft.}$

Hence the scale of the ordinates, such as  $KU$ , of the torque circle is known from all other ordinates from the above, and  
 $\frac{8210}{KU} = \frac{8210}{3.9} = 210.5 \text{ lb. ft. per 1 cm.}$

The maximum torque which the motor can exert before pulling up is represented by  $JY$ , and the maximum B.H.P. by  $JX$ .

The starting torque corresponding to the current  $CO$  is  $NM$ .

The Hayland diagram becomes more accurate the smaller the no load losses as compared with the copper losses, i.e. the larger the motor tested. The performance of the motor is slightly better than given by the diagram, while for motors smaller than for 4 or 5 H.P. the line  $MD$  should be drawn downwards from  $D$  at an arbitrary angle of about  $25^\circ$  to  $OA$  for greater accuracy,<sup>1</sup> in correcting the small error (slightly affecting the accuracy of the diagram) due to the greater proportion of no-load to load losses in small motors.

<sup>1</sup> For higher accuracy see Theory of Induction Motors by Diagram, G. OSMAN: *Zeitschr. Elektrotech. Wein*, 17, pp. 223-248 (1896), and Circle Diagram, by J. L. LA COUR (same journal), 21, pp. 613-645 (Nov. 1903).

**Note.**—If  $OG$  be drawn perpendicular to  $BF$  produced, then  $AB$  and  $OG$  will always be parallel at all loads and perpendicular to  $BC$ .

The sides  $OB$ ,  $BC$ , and  $CO$  of the triangle  $OBC$ , represent the stator current, rotor current, and magnetising current respectively. Now, in any electro-magnetic circuit the *total flux* = the *useful flux* + the *leakage flux*, while  $\frac{\text{total flux}}{\text{useful flux}}$  is called the *leakage factor*  $\nu$ , which is always greater than unity, and  $\frac{\text{leakage flux}}{\text{total flux}}$  is called the *coefficient of magnetic dispersion*  $\sigma$  which should be always much less than unity.

In the Heyland diagram, Fig. 102, the leakage factor

$$\nu = \frac{OA}{FA} = \frac{OF + FA}{FA} = \frac{OF}{FA} + 1$$

and the dispersion coefficient

$$\sigma = \frac{OF}{OA} = \frac{OA - FA}{OA} = 1 - \frac{FA}{OA} = 1 - \frac{1}{\nu}.$$

### (102) Complete Test for Efficiency, Slip, Power Factor, and Temperature Rise, of Three-Phase Induction Motors. (Sumpner and Weekes Method.)

**Introduction.**—This method,<sup>1</sup> due to Dr. W. F. Sumpner and R. W. Weekes, is an application of the principle of the ordinary Hopkinson test of a pair of d.c. dynamos (p. 228) to the test of a pair of three-phase induction motors. The arrangement, which entirely avoids the use of a brake, is extremely convenient for obtaining the temperature rise due to a long run at any particular load, and is shown in Fig. 103.  $M$  and  $G$  are the two machines to be tested, of which  $M$  is made the motor and  $G$  the generator. Their stator terminals  $T'$  are connected to the main supply  $SS$ , which is at the normal voltage and frequency required by  $G$  and  $M$ . A belt  $B$  drives the rotor pulleys, which must be of different diameters in order to enable the generator  $G$  to run at a higher speed, and the motor  $M$  at a lower speed than that of synchronism.

<sup>1</sup> Communicated by the authors to "Section G" of the British Association, August 22, 1904, at Cambridge.

If  $D_M$  and  $D_G$  are the diameters of these pulleys: then assuming the rotors are to remain short circuited during the test, the ratio  $\frac{D_M}{D_G}$  must be such as to cause the right slip for the load required. For example,—if the slip of each machine  $M$  and  $G$  = 2.5 % at full load, and if the probable efficiency of each = 85 %, then 15 % of the load is lost in each, and the overload of the motor  $M$  = 30 % roughly, corresponding with  $2.5 + \frac{30}{100} \times 2.5$  or 3.25 % roughly. The other machine  $G$  working as a generator develops full load and has a negative slip of 2.5 %.  $D_M$  and  $D_G$  must therefore differ by 2.5 + 3.25 or 5.75 %, assuming no mechanical slip of the belt  $B$  on the pulleys. If, however, 1.25 % be allowed for this, the pulleys must differ by 5.75 + 1.25 or 7 % in diameter, and the machines under test will, when switched into circuit, take a perfectly definite load which can be maintained for any length of time.

An interesting feature of the test lies in the fact that  $G$ , the machine used as the generator, gives current of about the same power factor as that of the current supplied to the motor  $M$ , while the current from the supply mains  $SS$  is the difference of the power components of the machine currents, together with the sum of the inductive components of these currents. Consequently, the power factor of the main current from  $SS$  is very small, and may be only  $\frac{1}{4}$  of that of the machine current, the main current from  $SS$  may be equal to, or greater than, that through the machines, while the actual power taken from  $SS$  may be less than  $\frac{1}{2}$  of that circulating round the machines  $G$  and  $M$ .

*Alteration of load* with two given pulleys can be obtained by alteration of resistance in the rotor circuits between starter and slip rings, or by using a low resistance starter which can stand the full load rotor currents. The  $C^2R$  losses in these rotor resistances, if appreciable, must be deducted from the power taken from  $SS$  in order to get the total loss in the two machines  $G$  and  $M$  and in the belt drive. The machines can be run at various loads, with resistance variation such as above, if the pulleys are chosen with sufficient difference to obtain the maximum slip required.

The magnitude of the mechanical slip at the pulleys is determined by the ratio of their circumferential speeds, a quantity difficult of determination with any accuracy in ordinary belt drives, but most easily found in the present method. Thus—

let  $S_r$  = frequency of the supply current,

$G_r$  = " " generator rotor current,

$M_r$  = " " motor rotor current;

then ratio of the rotor speeds  $R = (S_r + G_r) \div (S_r - M_r)$  and

ratio of the circumferential speeds of the pulleys =  $R \frac{D}{D_u}$

$G$  and  $M_r$  can be very accurately determined, and are each small compared with  $S_r$ , so that although  $S_r$  cannot be so accurately found, the value of  $R$  is not much affected by small errors in  $S_r$ .

The belt losses are easily determined, as shown in the table, and are caused by (a) extra bearing friction and in bending and driving the belt, (b) heating of the pulleys due to belt slip.

**Apparatus.**—The two similar three-phase induction motors to be tested: suitable pulleys and belt; four alternating current ammeters  $a_1, a_2, A_1, A_2$ ; an alternating current voltmeter  $V$ ; four wattmeters  $w_1, w_2, W_1, W_2$ ; source of three-phase supply  $SS$  of normal voltage and frequency for which the machines under test have been built; three-throw switch  $s_1, s_2, s_3$ .

**N.B.**—Switches must be used with the stator connections if the rotors are of the "short circuited" type, but are not wanted if the rotors are supplied with slip rings and starting resistance. Only two wattmeters will be needed if one is connected between neutral point and a terminal in the case of each machine, since in this case total power = 3  $\times$  power of one coil, which is sufficiently accurate for commercial work. Two wattmeters to each machine, as shown in Fig. 103, is, however, the best and most accurate arrangement, and has the additional advantage that the ratio of the readings of a pair of wattmeters gives the power factor independent of the usual method of getting the power factor from true watts  $\div$  apparent watts. With two wattmeters the reading of one will be owing to the low power factor of the supply current.

**Observations.**—(1) Connect up as shown in Fig. 103, and adjust these instruments to zero which require it.

(2) With the supply  $SS$  at the normal voltage and frequency needed for  $M$  and  $G$ , and the belt  $B$  off, close  $s_1, s_2, s_3$ , and start up  $M$  and  $G$ , which must run in the same direction. If they do not, stop them, change the connections at  $T$ , and start up again. Note the readings of all the instruments, and denote those of  $w_1$  and  $w_2$  by  $w_{g1}$  and  $w_{g2}$  respectively.

(3) Stop  $M$  and  $G$ , place the belt on, and start up again, with only one of the machines in circuit, and acting as a motor, but driving the other by belt with its stator excited and rotor open circuited. Note the readings of all the instruments, and denote those of  $w_1$ ,  $w_2$  by  $w_{s1}$  and  $w_{s2}$  respectively.

Thus the belt loss  $W_b = (w_{s1} + w_{s2}) - (w_{e1} + w_{e2})$ .

(4) In Tests 2 and 3 above, and in all future load tests, the slip of each machine can most conveniently and accurately be determined by measuring the frequency of the rotor currents by suitably shunting any ordinary low reading d.c. voltmeter to the

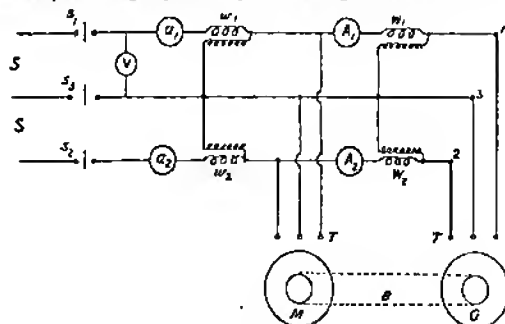


FIG. 103.

slip rings of the rotor, and noting the number of periods made by the pointer in, say, 20 seconds, these being slow enough to be easily counted. If  $M_p$  = number of periods per second, in, say, the case of the motor rotor currents and  $S_p$  = frequency of the supply current in periods per second, then the slip of the motor =

$$\frac{M_p}{S_p} \times 100\%$$

(5) Take readings at different loads, obtained by altering the resistance in the rotor circuit and tabulate as shown on page 293.

The values of the losses given in columns 31 and 32 are accurate enough for commercial purposes if the two machines are of the same make and of about the same rated full-load output and if subjected to the same voltage. A greater degree of accuracy may be obtained, however, by subdividing these



losses. In addition to the diameters of the pulleys indicating which machine is the motor and which the generator, the latter is the one which must always run at the higher speed. If the belt is removed and the machines run light, the wattmeters  $W_1$  and  $W_2$  will read negatively if  $G$  is the generator.

Column 44 is obtained from the curve Fig. 104, which is drawn in the following manner.

The ratio of the two readings of wattmeters  $W_1$  and  $W_2$ , connected as shown in Fig. 103, varies from +1 to -1. Hence the power factor  $\cos. \phi$  can be calculated from the readings of  $W_1$  and  $W_2$  by substituting different values of  $\phi$  (the angle of lag) between current and voltage in the formula shown.

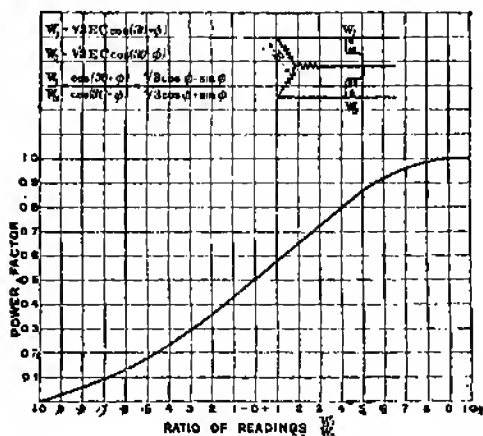


FIG. 104.

The value of  $\frac{W_1}{W_2}$  so found plotted against the value of  $\cos. \phi$  gives the curve, Fig. 104. As an example of the application of this curve, let  $W_1 = 6800$  watts,  $W_2 = 18000$ , then  $\frac{W_1}{W_2} = 0.37$  and  $\cos. \phi = 0.77$ . Again, let  $W_1 = (-) 2000$  watts,  $W_2 = 4000$ , then  $\frac{W_1}{W_2} = (-) 0.50$ , and  $\cos. \phi = 0.18$ .

Machine No. ....		Maker ....		Full Load—Volts ....		Amps. ....		Speed .... used as Generator G.	
Machine No. ....		Maker ....		Full Load—Volts ....		Amps. ....		Speed .... used as Motor M.	
No. ....		Resistance of each: Stator Coil ....		Rotor Coil ....		Rotor Coil ....		Diam. of Motor Pulley $D_M$ = ....	
In Test No. 3 $w_1 =$ ....		Resistance of each: Stator Coil ....		Rotor Coil ....		Rotor Coil ....		Diam. of Gear Pulley $D_G$ = ....	
In Test No. 3 $w_2 =$ ....		Resistance of each: Stator Coil ....		Rotor Coil ....		Rotor Coil ....		Diam. of Gear Pulley $D_G$ = ....	
Point of Reading.	Time in Hours from Start.	Volts $V$ .		Amps.		Wattmeter Reading.		True Watts.	
		$v_1$	$v_2$	$a_1$	$a_2$	$w_1$	$w_2$	$W_1$	$W_2$
1	2	3	4	5	6	7	8	9	10
									11
Wattmeter Reading.		True Watts.		Output of Generator G $\frac{W_1 + W_2}{2}$		No. of Periods of Rotor Currents in 20 Secs.		Frequency of Rotor Currents.	
Amps. $A$ .		$dW_1$	$dW_2$	$W_1$	$W_2$	$M_1$	$G_1$	$\frac{M_1}{20}$	$\frac{G_1}{20}$
12	13	14	15	16	17	18	19	20	21
									22
Electro Magnetic Slip of Mechanical Slip $\frac{M_1 - M_2}{M_1 + M_2} \times 100 = \frac{G_1 - G_2}{G_1 + G_2} \times 100 = M\%$		Belt Loss $\frac{G_1 + G_2}{2} \times 100 = \frac{W_1 + W_2}{2} \times 100 = G\%$		Temperature in Degrees F. or C. of the		Total Losses in		Motor Input $\frac{W_1 + W_2}{2} = M_h$	
23		24		25		26		27	
28		29		30		31		32	
33		34		35		36		37	
38		39		40		41		42	
43		44		45		46		47	
48		49		50		51		52	
53		54		55		56		57	
58		59		60		61		62	
63		64		65		66		67	
68		69		70		71		72	
73		74		75		76		77	
78		79		80		81		82	
83		84		85		86		87	
88		89		90		91		92	
93		94		95		96		97	
98		99		100		101		102	
103		104		105		106		107	
108		109		110		111		112	
113		114		115		116		117	
118		119		120		121		122	
123		124		125		126		127	
128		129		130		131		132	
133		134		135		136		137	
138		139		140		141		142	
143		144		145		146		147	
148		149		150		151		152	
153		154		155		156		157	
158		159		160		161		162	
163		164		165		166		167	
168		169		170		171		172	
173		174		175		176		177	
178		179		180		181		182	
183		184		185		186		187	
188		189		190		191		192	
193		194		195		196		197	
198		199		200		201		202	
203		204		205		206		207	
208		209		210		211		212	
213		214		215		216		217	
218		219		220		221		222	
223		224		225		226		227	
228		229		230		231		232	
233		234		235		236		237	
238		239		240		241		242	
243		244		245		246		247	
248		249		250		251		252	
253		254		255		256		257	
258		259		260		261		262	
263		264		265		266		267	
268		269		270		271		272	
273		274		275		276		277	
278		279		280		281		282	
283		284		285		286		287	
288		289		290		291		292	
293		294		295		296		297	
298		299		300		301		302	
303		304		305		306		307	
308		309		310		311		312	
313		314		315		316		317	
318		319		320		321		322	
323		324		325		326		327	
328		329		330		331		332	
333		334		335		336		337	
338		339		340		341		342	
343		344		345		346		347	
348		349		350		351		352	
353		354		355		356		357	
358		359		360		361		362	
363		364		365		366		367	
368		369		370		371		372	
373		374		375		376		377	
378		379		380		381		382	
383		384		385		386		387	
388		389		390		391		392	
393		394		395		396		397	
398		399		400		401		402	
403		404		405		406		407	
408		409		410		411		412	
409		410		411		412		413	
410		411		412		413		414	
411		412		413		414		415	
412		413		414		415		416	
413		414		415		416		417	
414		415		416		417		418	
415		416		417		418		419	
416		417		418		419		420	
417		418		419		420		421	
418		419		420		421		422	
419		420		421		422		423	
420		421		422		423		424	
421		422		423		424		425	
422		423		424		425		426	
423		424		425		426		427	
424		425		426		427		428	
425		426		427		428		429	
426		427		428		429		430	
427		428		429		430		431	
428		429		430		431		432	
429		430		431		432		433	
430		431		432		433		434	
431		432		433		434		435	
432		433		434		435		436	
433		434		435		436		437	
434		435		436		437		438	
435		436		437		438		439	
436		437		438		439		440	
437		438		439		440		441	
438		439		440		441		442	
439		440		441		442		443	
440		441		442		443		444	
441		442		443		444		445	
442		443		444		445		446	
443		444		445		446		447	
444		445		446		447		448	
445		446		447		448		449	
446		447		448		449		450	
447		448		449		450		451	
448		449		450		451		452	
449		450		451		452		453	
450		451		452		453		454	
451		452		453		454		455	
452		453		454		455		456	
453		454		455		456		457	
454		455		456		457		458	
455		456		457		458		459	
456		457		458		459		460	
457		458		459		460		461	
458		459		460		461		462	
459		460		461		462		463	
460		461		462		463		464	
461		462		463		464		465	
462		463		464		465		466	
463		464		465		466		467	
464		465		466		467		468	
465		466		467		468		469	
466		467		468		469		470	
467		468		469		470		471	
468		469		470		471		472	
469		470		471		472		473	
470		471		472		473		474	
471		472		473		474		475	
472		473		474		475		476	
473		474		475		476		477	
474		475		476		477		478	
475		476		477		478		479	
476		477		478		479		480	
477		478		479		480		481	
478		479		480		481		482	
479		480		481		482		483	
480		481		482		483		484	
481		482		483		484		485	
482		483		484		485		486	
483		484		485		486		487	
484		485		486		487		488	
485		486		487		488		489	
486		487		488		489		490	
487		488		489		490		491	
488		489		490		491		492	
489		490		491		492		493	
490		491		492		493		494	
491		492		493		494		495	
492		493		494		495		496	
493		494		495		496		497	
494		495		496		497		498	
495		496		497		498		499	
496		497		498		499		500	
497		498		499		500		501	
498		499		500		501		502	
499		500		501		502		503	
500		501		502		503		504	
501		502		503		504		505	
502		503		504		505		506	
503		504		505		506		507	
504		505		506		507		508	
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519		520		521		522		523	
520		521		522		523		524	
521		522		523		524			

### (103) Relation between Efficiency, Slip, Torque, Load, etc., in an Induction Motor with Variable Rotor Circuit Resistance.

**Introduction.**—The present test is obviously just an extension of, and similar in almost every way to, test No. 100, which is therefore repeated here but with different amounts of the starting resistance ( $r$ ) in circuit instead of it being all cut out to short-circuit as in that test. Consequently there will be one set of curves, such as was obtained in test No. 100, for each different value of rotor circuit resistance used in the present investigation.

Further, if, say, five different rotor circuit resistances were used, giving five complete sets of curves as in test No. 100, then any of the variables plotted, say, against load, for the different constant rotor resistances can be transferred and replotted against rotor resistance, e. g. there would be five efficiency-load curves, then if a straight line was drawn through, say, full-load point, parallel to the axis of efficiency, and cutting the five efficiency curves; the five different efficiencies obtained by the five intersection points can be plotted against the five values of rotor resistance of the efficiency-load curves to give a curve of five points between efficiency and rotor resistance only.

If  $E_s$  = E.M.F. induced in each stator circuit due to the rotating field,

$N_s N_r$  = number of turns per phase in each stator and rotor winding respectively,

$\omega_1 \omega_2$  = angular velocities of rotating stator field and rotor respectively,

$r_R$  = resistance of each rotor circuit,

$L_R$  = self-induction of each rotor circuit,

$p$  = number of pairs of poles in the rotating stator field,

$f$  = frequency of the stator supply voltage and currents,

$K$  = the slip.

Then we have  $K = \frac{\omega_1 - \omega_2}{\omega_1}$  and the frequency of the induced

E.M.F. and currents in the rotor circuits will =  $\frac{\omega_1 - \omega_2}{\omega_1} \times f =$

$Kf$  = slip in cycles per sec., and it can be shown that the running torque  $T$  is given by the relation

$$T = \frac{N_s^2 E_s^2 r_R K}{N_s^2 \omega_1 (K^2 (2\pi f L_R)^2 + r_R^2)} = \frac{N_s^2 E_s^2 r_R K}{N_s^2 2\pi f (K^2 (2\pi f L_R)^2 + r_R^2)}$$

where  $f/p$  = speed of the stator rotating field in  
revs. per sec.,

and  $2\pi f/p = \omega_1$  = its angular velocity,

$K2\pi f L_R$  = reactance per rotor circuit when in  
motion and which is  $\propto$  to slip,

and  $K^2 (2\pi f L_R)^2 + r_R^2$  = (impedance)<sup>2</sup> per rotor circuit when in  
motion.

Further, if  $A_R$  = current per phase in the rotor, and  $F$  = leakage flux, then the coefficient of self-induction per phase of the rotor =  $\frac{(N_s)^2 F}{10^9 \text{ henries}}$ , which can also be calculated from the shape of slots and winding in them.

The above expression for  $T$  shows us that the running torque  $T$  of the induction motor is  $\propto$  to the square of the stator voltage, *i.e.* to the square of the stator flux, and increases as both the supply frequency and reactance per phase of the rotor decreases, becoming a maximum (*hcf*) when

$$K = \frac{r_R}{2\pi f L_R} \text{ and } T = \frac{N_s^2 E_s^2}{N_s^2 2\pi f 2 (2\pi f L_R)} = \frac{N_s^2 E_s^2 p}{8 N_s^2 \pi^2 f^2 L_R}$$

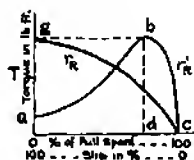


FIG. 105.

Thus, since the last expression for the maximum value of the running torque does not contain  $r_R$ , we see that it is constant and independent of the rotor circuit resistance, but for different values of rotor resistance will attain the same maximum value at a different slip, as indicated in Fig. 105. The motor starts

at 0 with 100% slip and reaches the same maximum running torque  $bd = og$  for slips of  $cd\%$  and  $co = 100\%$  (i. e. full speed) respectively, with rotor circuit resistances  $r_2$  and  $r_2'$ ; since the stator current depends on the constant no-load current and rotor current, and the latter will always be the same for a given torque, it follows that each value of torque will have a definite stator current which is independent of the rotor resistance.

**Apparatus.**—Precisely that for the preceding efficiency-load test No. 100, the starting resistance in the rotor circuit being of sufficient current-carrying capacity to enable it to carry, without overheating, the full-load rotor currents.

**Observations.**—Connect up as in Fig. 100, and carry out the tests precisely as directed in that test, for as many different values of starter resistance as possible.

Tabulate as shown on p. 276, adding two extra columns for values of starter resistance ( $r$ ) and total rotor circuit resistance  $r_2 = (r_2' + r)$  respectively.

Plot the following curves having torque  $T$  in lb.-ft., and rotor current  $A_2$  as ordinates with percentage of full speed (or slip), and stator current  $A_1$  respectively as abscissae for each value of rotor circuit resistance ( $r_2$ ).

Also curves having efficiency, power factor, slip and true stator watts absorbed as ordinates with B.H.P. as abscissae for two widely different values of  $r_2$ .

**Inferences.**—From a careful study of the numerical results and curves state clearly what can be deduced.

#### (104) Relation between the Starting Torque, Current, Voltage, and the Rotor Circuit Resistance of an Induction Motor. (Rotor at Standstill.)

**Introduction.**—Under these conditions the slip will be 100%, since the speed is zero. The power absorbed will include both iron and copper losses, and the motor will approximate to a static transformer with a non-inductive secondary load.

Now the frequency  $f$  of the stator supply will also be that

of the rotor circuits when at rest, and if we put  $K=1$  in the expression for the running torque (p. 295), since the rotor is now stationary, it will be seen that the starting torque  $T_0$  is given by the relation

$$T_0 = \frac{N_s^2 E_s^2 r_R}{N_s^2 2\pi f (2\pi f L_R)^2 + r_R^2} \cdot \frac{1}{p}$$

where  $\frac{f}{p}$  = speed of the rotating field in revs. per sec. and  $\frac{2\pi f}{p}$  its angular velocity,  $(2\pi f L_R)^2 + r_R^2$  = the square of the impedance, and  $2\pi f L_R$  = the reactance per phase of the rotor when at rest. From the above relation we see that the starting torque  $T_0$  is  $\propto$  to the square of the stator voltage, i.e. to the square of the stator flux, and increases as both the supply frequency and reactance per phase of the rotor decreases, becoming a maximum when  $2\pi f L_R = r_R$ .

For this last condition—

$$T_0 = \frac{N_s^2 N_R^2 p}{2 N_s^2 2\pi f r_R} = \frac{N_R^2 p}{4 N_s^2 \pi} \times \frac{E_s^2}{f r_R}, \text{ i.e. inversely } \propto \text{ to } r_R$$

we therefore have the following most important deductions, namely, that for a given supply frequency, the starting torque is a maximum when the resistance and reactance of the rotor circuits are equal and each as small as possible. Since the rotor currents are a maximum at starting, the present test enables the maximum value of the starting resistance to be obtained under either of two conditions: namely, (1) for maximum starting torque, or (2) for maximum safe starting rotor current. In the former, by measuring the values of  $L_R$  and  $r_w$  per phase winding of the rotor we know that for maximum starting torque  $2\pi f L_R$  must =  $r_w + r$ , whence the external starter resistance must have a maximum value  $r = 2\pi f L_R - r_w$  ohms per phase.

In the latter, if  $V_R$  = the standstill slip-ring voltage at normal stator volts and frequency, then  $\frac{V_R}{\sqrt{3}}$  = the standstill volts per phase winding, whence  $r = \frac{V_R}{\sqrt{3} I_R}$  ohms per phase for a maximum safe starting rotor current  $I_R$ . The gradation of  $r$

between this maximum value and 0 depends on the number of switch contacts and sections chosen.

**Apparatus.**—That detailed for the no-load short-circuit test No 98, using an induction motor having a slip-ring rotor connected to the usual form of three-phase equal variable starting resistance of a current-carrying capacity sufficient to allow the necessary time for taking readings without overheating. In addition, a block brake and lever, preferably similar to that shown in Fig. 95, will be needed to measure the torque exerted by the shaft.

**Observations.**—(1) Connect up as in Fig. 100, levelling and adjusting to zero such instruments as need it. On starting up see that all lubricating arrangements are feeding properly.

**Starting Torque with Rotor Circuit Resistance for a Constant Supply Voltage and Frequency.**—(2) Adjust the supply frequency  $f$  to the normal value for the motor and the supply voltage  $V_s$  to some convenient value, if necessary lower than the normal value for the motor in order to avoid excessive rotor currents and keep both constant. Then read the spring balance and all other instruments *as quickly as possible*, when ( $c$ ) is moved one contact stud at a time from its "full in" position to such a position nearer that of short circuit at which the rotor current  $A_r$  reaches a safe overload value. Finally measuring the resistance of each rotor circuit corresponding to each contact-stud position.

**Starting Torque with Supply Frequency for Constant Rotor Circuit Resistance and Supply Voltage.**—(3) With the supply voltage  $V_s$  and starter resistance  $r$  adjusted to convenient values for giving safe maximum rotor currents and kept constant, read the spring balance and all the other instruments *as rapidly as possible* at each of a series of supply frequencies ( $f$ ) between the maximum and minimum values possible and convenient.

**Starting Torque with Supply Voltage for Constant Rotor Circuit Resistance and Frequency.**—(4) With supply frequency and starter resistance  $r$  adjusted to convenient constant values, read the spring balance and all instruments *as rapidly as possible* at each of a series of supply voltages  $V_s$  between maximum and minimum values giving safe maximum rotor currents, and tabulate all your results as follows—

Motor: No. . . . . Type . . . . . Maker . . . . .  
 Fullload: Volts = . . . . . Amps = . . . . . Speed = . . . . . Frequency = . . . . .  
 Res. per phase winding of rotor  $r_R$  = . . . . . ohms.  
 Leverage of Spring Balance from Shaft Centre ( $l$ ) = . . . . . ft.

Source Full at Run	Starting Torque, $T_0 = \frac{W}{g} \cdot \frac{R}{l}$	Frequency $f$	Volts $V_s$	Amps. $A_s$	True Watts			Apparent Watts $V_s A_s$	Power Factor $\cos \phi = \frac{W}{V_s A_s}$	Angle of Lag $\phi$	Rotor		
					$w_1$	$\pm w_2$	Total $w_1 \pm w_2$				Volts $V_R$	Amps. $A_R$	Values of $\frac{V_s^2}{f^2 r_R}$

(5) Plot curves having values of  $A_s$ ,  $A_R$ , and  $T_0$  as ordinates, with values of  $(r_R)$  from obs. 2 as abscissae, also curves having  $T_0$  as ordinates with (a) frequency ( $f$ ) from obs. 3, and (b) stator supply volts ( $V_s$ ) from obs. 4, (c) stator amps.  $A_s$ , and (d) rotor amps.  $A_R$ . An additional column for values of  $T_0 \div \left( \frac{V_s^2}{f^2 r_R} \right)$  might be added to this table in order to see how nearly this ratio is constant, i. e. how nearly the starting torque is  $\propto \frac{V_s^2}{f^2 r_R}$ .

**Inferences.**—From a careful study of the numerical results and curves, carefully point out all that can be deduced.

### (105) Determination of the Efficiency, B.H.P., and other Characteristics of Single Phase Alternating Current Commutator Motors.

**Introduction.**—The comparatively small starting torque of the induction motor to that necessary for electric traction work has led in recent years to the production, improvement, and utilization on an increasing scale of the so-called alternating-current commutator motor. It is well known that any ordinary direct-current series or shunt-wound electric motor will run in one and the same direction whichever way the supply current flows through it, for with every reversal of the supply current, the magnetization of both field and armature will also be simultaneously reversed, and the motor will continue to run as if nothing had been changed. From this it follows that any ordinary D.C. machine will run as a motor when supplied with



A.C., though inefficiently owing (1) to the large eddy-current loss due to heavy eddy currents which would be set up in the solid field system by reason of the rapid reversal of the magnetization, and (2) the demagnetizing effect of such currents on the field. If, however, the field system is well laminated, like the armature of any machine always is, the machine would run with reasonable efficiency on an A.C. supply, but will develop less power than when run with D.C., of the same mean voltage, owing to the smaller current and flux, and to the larger internal losses due to eddy currents and hysteresis resulting from an A.C. supply.

The field magnets of A.C. commutating motors are either bi-polar or multi-polar, whether of the projecting-pole form used in D.C. machines, or of the cylindrical form with uniform air-gap as used in induction motors, and with definite polarity produced by the windings but not otherwise so evident. The armature, however, presents the usual appearance of D.C. forms, although, along with its commutator, embodying features mentioned later and necessary for ensuring satisfactory operation.

These features will be appreciated after a brief consideration of the actions taking place in the machine, but at the outset it should be realized that a single-phase series-wound commutator motor, built on the best possible lines for a given voltage supply, will operate in every way as well, but even more efficiently when run from a D.C. supply of the same voltage. In fact, such motors have to run on A.C. in some parts and on D.C. in other sections of certain tramway undertakings.

Now, considering such a series-wound motor with (for simplicity) a two-pole field, and hence with one pair of brushes, with a D.C. supply, producing a *unidirectional field in the poles and through the armature*, there will be set up a *unidirectional induced* potential difference (P.D.) having its maximum value between the brushes, i.e. along the "diameter of commutation" which, with the motor running light, will be coincident with the "neutral axis" and perpendicular to the direction of the fixed field. This induced P.D. (or "back E.M.F.") is set up solely by reason of the forced rotation of the armature conductors across the field, by the supply current flowing in them, and with a given field is entirely due and

directly  $\propto$  to the speed ( $n$ ) of rotation. On the other hand, with an A.C. supply producing an *alternating field in the poles and through the armature*, there will be set up two distinct alternating P.D.s: namely, (1) the induced P.D. having its maximum value between the brushes exactly as mentioned above, and with a given field entirely due and directly  $\propto$  to the speed ( $n$ ) of rotation; it is in phase with the field and also practically with the current, and consequently not in direct opposition of phase with the supply E.M.F., and (2) the self-induced P.D. having its maximum value between two points in the armature winding on a diameter perpendicular to the diameter of commutation. This self-induced P.D. is set up solely by reason of the *transformer action* due to the armature conductors cutting the alternating field, and will lag in phase behind the field flux by an angle of  $90^\circ$ . Its magnitude will depend only on the strength and rate of reversal (*i.e.* the frequency  $f$ ) of the alternating field, and in no way on whether the armature rotates or is stationary. It has no effect on the action of the motor, nor on the supply; consequently, due to the main field, in the rotating armature of a single-phase commutator motor, there are induced two entirely distinct E.M.F.s—one caused only by and directly  $\propto$  to the speed of rotation, the other caused only by transformer action and directly  $\propto$  to the supply frequency.

Now, when a current flows through the armature, the latter becomes a powerful electro-magnet, the two halves of the winding in parallel between the brushes producing two similar semi-circular electro-magnets having a consequent north and a consequent south pole situated in the diameter of commutation, and at a distance apart equal to the diameter of the armature core. The flux of this armature magnetization will be in phase with the current, and have a direction therefore perpendicular to the main field flux, or in line with the diameter of commutation, giving rise to the phenomenon commonly known as *armature reaction*. It will react on the main flux in three ways: (1) by distorting and dragging it round in the direction of rotation, (2) by inducing in the armature conductors, as they rotate through it, an E.M.F. along an axis parallel to the main field, but which will not in any way affect the action of the motor,

(3) by inducing, through transformer action on the armature conductors, an E.M.F. of self-induction  $90^\circ$  in phase behind the current and acting along an axis joining the two brushes. The value of this self-induced or reactance voltage of the armature is  $L_a 2\pi f A$  where  $L_a$  = coefficient of self-induction of the armature winding carrying a current  $A$ , and  $f$  = the frequency of the current  $A$ , which in this case is that of the supply to the motor. Since the motor is series wound, the same current  $A$  will flow in the field-winding which will have a coefficient of self-induction  $L_f$ . Consequently the series field coils will introduce into the circuit a self-induced, or back, or reactance voltage  $= L_f 2\pi f A$ . Thus the total reactance voltage of the motor will  $= 2\pi f A (L_f + L_a)$ . Now the reactance of the machine has the disadvantage of reducing the power factor of the circuit, and should therefore be minimized as far as possible.

That due to the field coils cannot be reduced, because the chief cause of its existence, viz. the flux, is also necessary for the operation of the machine as a motor.

The reactance of the armature can, and is, compensated for by an additional winding on the field system midway between the main field windings, and producing a flux equal and opposite to the reactance field of the armature, and which is connected either in series with the circuit or short-circuited on itself. In either case the effect is the neutralization of the armature reaction flux and reactance and an increase in power factor. Again, although the self-induced voltage in the armature coils, due to transformer action and main field has no effect on the action of the motor, it has an effect on the commutation. For example, an armature coil undergoing commutation is short-circuited by the brush while inactive, i. e. generating no E.M.F. by reason of its rotation across the field. Since, however, in an A.C. motor, the coil by transformer action has, during commutation, a self-induced E.M.F., this will produce in it, when short-circuited by the brush, a heavy current which when broken as the segments leave the brush will cause sparking and the deterioration of the commutator.

Now, the self-induced E.M.F. of a coil decreases with a decrease in the number of turns, and if the circuit of the coil is broken before the current has time to attain its full value the

spark will be decreased. Hence in commercial single-phase commutator motors, sparking is minimized by (a) having as few a number of turns per armature coil as possible, (b) an increased number of coils and peripherally narrower commutator segments and brushes, (c) as small a supply frequency as possible, (d) brushes of special composition. The narrower segment in (b) reduces the time during which an armature coil is short-circuited and reduces the short-circuit current in it.

The single-phase A.C. motor possesses much the same characteristics as the D.C. form, being a variable speed motor, giving maximum torque on starting which decreases with increase of speed, and is  $\propto$  to armature current, but independent of power factor. It will tend to race in speed on suddenly removing the load. Further, since the current is simultaneously

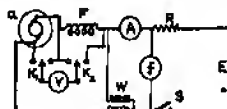


FIG. 106.

reversed in armature and field, the torque will be unidirectional though pulsating.

**Apparatus.**—An A.C. supply  $E$ , preferably a motor-driven alternator having a speed and field control independently variable between wide limits; ammeter  $A$ ; variable non-inductive rheostat  $R$ ; frequency meter ( $f$ ); voltmeter  $V$  with two two-way keys  $K_1$ ,  $K_2$ ; wattmeter  $W$ ; switch  $S$ ; and single-phase commutator motor, to be tested, of which the series field windings are  $F$  and ( $a$ ) the armature.

**Observations.**—(1) Connect up as in Fig. 106, levelling and adjusting to zero such instruments as need it. N.B.—With a town's supply for  $E$ , the rheostat  $R$  will be needed to start up  $M$  and for regulating the current afterwards, otherwise with a motor alternator this may be done by field excitation.

(2) With  $R$  or the alternator field rheostat full in, and the armature shaft clamped to prevent it rotating, close  $S$  and adjust the frequency  $f$  to the normal value for the motor. Now



(9) Plot the following curves—

From obs. 4 between voltage  $V$  as abscissa with speed  $A$  and  $W$  as ordinates.

From obs. 5 between frequency  $f$  as abscissa with speed  $A$  and  $W$  as ordinates.

From obs. 6 and 7 between loads  $H_1$  as abscissa with values of  $\Sigma$ ,  $\cos \phi$ ,  $H_2$  and  $A$  as ordinates.

From obs. 8 between speed as abscissa with values of  $\Sigma$  and  $H_1$  as ordinates.

From obs. 8 between torque as abscissa and values of speed and  $A$  as ordinates.

**Inferences.**—State clearly all that can be deduced from the tabular results and curves.

### (106) Relation between the Field Excitation and Armature Current, or the "V" and other Curves, of a Synchronous Alternating-Current Motor Running Light or at Constant B.H.P.

**Introduction.**—All alternators, whether single or polyphase, are reversible machines, and will run as motors synchronously with the periodicity of the A.C. supply to their armatures, the field system being in all cases supplied with a separate source of direct current.

Synchronous motors are, however, *not self-starting*, for at every succeeding rapid reversal of the A.C. supply, the armature coils receive equal impulses but in opposite direction, and hence there is no resultant torque. If, however, the motor is first started up and run by some other driving source of power, at such a speed that any armature conductor passes through the distance between the centres of two poles (*i.e.* the pitch) in half the periodic time of the A.C. supply, then on switching it on to the supply it will continue to run as an efficient A.C. motor in dead synchronism with the supply frequency, irrespective of load, so long as this is not sufficient to pull it out of step with the supply current.

A single-phase synchronous motor therefore develops an alter-

nating armature polarity and torque which reverses with the rapidity of reversal of the A.C. supply, thus producing unidirectional rotation. On the other hand, the currents in the phase windings of a polyphase synchronous motor combine so as to form a constant polarity of fixed position relatively to that of the field, so causing a *unidirectional torque* and rotation.

**Apparatus.**—Sources of A.C. supply  $E_1$  to synchronous motor  $M$ , and of D.C. supply  $E_2$  to starting motor ( $m$ ) and field of  $M$ ; switch  $S$ ; lamps  $L_1L_2$ ; A.C. ammeter  $A$ , voltmeter  $V$ , wattmeter  $W$ ; D.C. ammeter  $a$ , voltmeter  $v$ . Field ammeter  $\sigma$ , rheostats  $rh$  and  $r_s$ , switches  $S_f$  and  $S_m$  with starter or main variable resistance ( $r$ ).

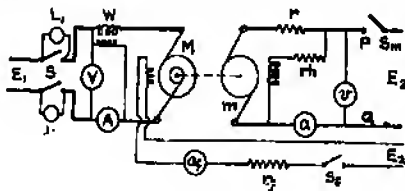


FIG. 107.

**Note**—The lamps  $L_1L_2$  should be stamped for a voltage, each equal or even 10% higher than that of  $M$ , so as to avoid burning them out while synchronising.

**Observations.**—(1) Connect up as shown in Fig. 107, levelling and adjusting to zero such instruments as require it. On starting the machines, see that their lubricating arrangements are working properly.

(2) The Synchronising or starting up of the A.C. motor under test can be effected as follows: with  $S$  and  $S_f$  open and ( $r$ ) off, if a starter, or "full in," if a variable rheostat, close  $S_m$  and operate ( $r$ ) so as to start the machines up to about the normal speed of  $M$ ; now close  $S_f$  and adjust  $r$ ,  $rh$  and  $r_s$  until  $V$  indicates the same voltage as that of the supply  $E_1$ , and the lamps  $L_1L_2$  cease to blink and go out definitely with a slow period. At this moment close  $S$  and open  $S_m$ , when the A.C. machine  $M$  will continue to run as a synchronous A.C. motor at a speed entirely governed by, and directly proportional to, the supply frequency.

**Note.**—At the above moment of closing  $S$ , the back E.M.F. ( $V$ ) of  $M$  will be not only practically equal to, but also exactly opposite in phase with (i.e. differ by  $180^\circ$  from), that of the supply  $E_1$ .

The starting up may also be effected by one of the special forms of synchroniser now made for the purpose, e.g. the rotatory type or synchroscope of Mesara, Everett, Edgcombe & Co., the characteristics of which are as follows: with the supply and the motor connected to the respective pairs of terminals on the synchroscope, the speed and field of  $M$  are adjusted until the frequency of  $M$  = that of the supply (indicated by the rotating pointer coming to rest), and the voltage of  $M$  is equal and opposite in phase to that of the supply (indicated by the pointer taking the vertical position); under these conditions, the dial will show a white light and  $S$  can be closed. Briefly, therefore, *close main switch when pointer stops vertically and white light shows*. If  $M$  is running too fast, the pointer rotates clockwise and a red light shows, whereas if  $M$  is running too slow, the pointer rotates counter-clockwise and a green light shows.

Two- and three-phase machines are synchronised by the same single phase instrument with its 2 pairs of terminals connected across any one phase, either side of the main switch contacts of that particular phase. With the motor  $M$  under test running synchronously with the A.C. supply, the following very interesting and important investigations can be made, namely—

(3) With  $S_m$  open and  $r$  and  $rk$  "full in,"  $M$  will (unless coupled to and released from  $m$  by an electro-magnetic clutch) simply be turning it against the small windage, brush, and bearing frictions, and will therefore practically be *running light* itself. For this no-load condition at normal supply frequency and voltage adjust  $r_f$  to obtain *minimum reading on A*, and note simultaneously that of  $V$ ,  $W$ ,  $a_f$ , and the speed.

(4) Next vary  $r_p$  and hence the exciting current ( $a_f$ ), by a series of steps, *above and below* the value found in obs. 3, as will raise  $A$  to a value *not exceeding 25% over load*, in each case noting  $V$ ,  $W$ ,  $a_f$ ,  $A$  and the speed at each excitation. The supply voltage  $V$  and frequency being kept constant throughout at the value of obs. 3.

(5) Repeat obs. 3 and 4 for constant B.H.P. load outputs



from  $M$  of say  $\frac{1}{2}$ ,  $\frac{1}{3}$ ,  $\frac{1}{4}$  and full load respectively at the same constant supply volts and frequency, taking that value of  $a$ , giving minimum main current  $A$  as the starting point of the "up and down series" of  $(a)$ .

Note.—The brake load can most conveniently be taken up electrically in the coupled D.C. starting motor  $m$  by causing it to act as a D.C. generator and send current through a suitable current rheostat to be connected in series with a switch (neither shown in Fig. 107) across the points  $P$  and  $Q$ . In this case  $(r)$  must be short-circuited and special precaution taken to keep  $S_m$  open.

The product  $v \cdot a$  = the power absorbed in the added rheostat, and, if the efficiency of  $M$  is known, the actual B.H.P. developed by  $M$  is at once obtainable, otherwise with constant excitation of  $(a)$ , the power absorbed by it will be roughly  $\propto$  to the currents  $(a)$  developed, and therefore to the B.H.P. given by  $M$ . Tabulate all results as follows—

Synchronous Motor: No. . . . . Maker . . . . . Type . . . . .  
 Full load (normal): B.H.P. = . . . . with Amps. at . . . . Volts, and Speed = . . . . r.p.m.  
 D.C. Starting Motor Full load Amps. = . . . . Volts = . . . . Speed = . . . .  
 Efficiency  $\eta$  = at . . . . load.

Supply.		Exciting Amps. $a$ .	Armature.			Power Factor $\cos \phi = W/A \cdot V$ .	Angle of Phase Difference $\phi$ .	Speed in r.p.m.	D.C. Starting Motor as load.		
Frequency $f$ .	Voltage $V$ .		Amps. $A$ .	Apparent Watts $A \cdot V$ .	True Watts $W$ .				Volts $v$ .	Amps. $a$ .	B.H.P. of $M$ $= \frac{v \cdot a}{746}$ .

(6) Plot curves for running light and for each load on  $M$  having (1) amps  $A$ , (2) power factor ( $\cos \phi$ ), and (3) watts  $W$  as ordinates with exciting current  $(a)$  as abscissae in each case.

Inferences.—From a careful study of the shapes of the curves and of the tabular results, state what can be deduced.

from  $M$  of say  $\frac{1}{2}$ ,  $\frac{1}{3}$ ,  $\frac{1}{4}$  and full load respectively at the same constant supply volts and frequency, taking that value of  $a$ , giving minimum main current  $A$  as the starting point of the "up and down series" of  $(a)$ .

Note.—The brake load can most conveniently be taken up electrically in the coupled D.C. starting motor  $m$  by causing it to act as a D.C. generator and send current through a suitable current rheostat to be connected in series with a switch (neither shown in Fig. 107) across the points  $P$  and  $Q$ . In this case  $(r)$  must be short-circuited and special precaution taken to keep  $S_m$  open.

The product  $v \cdot a$  = the power absorbed in the added rheostat, and, if the efficiency of  $M$  is known, the actual B.H.P. developed by  $M$  is at once obtainable, otherwise with constant excitation of  $(a)$ , the power absorbed by it will be roughly  $\propto$  to the currents  $(a)$  developed, and therefore to the B.H.P. given by  $M$ . Tabulate all results as follows—

Synchronous Motor: No. . . . . Maker . . . . . Type . . . . .  
Full load (normal): B.H.P. = . . . . . with Amps. at . . . . . Volts, and Speed = . . . . . r.p.m.  
D.C. Starting Motor Full load Amps. = . . . . . Volts = . . . . . Speed = . . . . .  
Efficiency % = at . . . . . load.

Supply.		Exciting Amps. $a$ .	Armature.			Power Factor $\cos \phi = W/A \cdot V$ .	Angle of Phase Difference $\phi$ .	Speed in r.p.m.	D.C. Starting Motor as load.		
Frequency $f$ .	Voltage $V$ .		Amps. $A$ .	Apparent Watts $VA$ .	True Watts $W$ .				Volts $v$ .	Amps. $a$ .	B.H.P. of $M$ $= \frac{v \cdot a}{746}$ .

(6) Plot curves for running light and for each load on  $M$  having (1) amps  $A$ , (2) power factor ( $\cos \phi$ ), and (3) watts  $W$  as ordinates with exciting current  $(a)$  as abscissae in each case.

Inferences.—From a careful study of the shapes of the curves and of the tabular results, state what can be deduced.

**(107) Efficiency and B.H.P., with other Characteristics, of a Synchronous Motor run from a Constant Voltage and Frequency Supply at Constant Excitation.**

**Introduction.**—In view of the peculiar relations existing between the excitation and other factors as determined in the last test, and the use of the synchronous machine for raising the average working power factor of a supply system, it is both interesting and important to see what effect load has on the same factors. This is apparent when determining the efficiency-load curve of the machine in the present test.

**Apparatus.**—Precisely that for test, No. 106.

**Observations.**—Carry out obs. 1, 2, and 3 of test, No. 106, exactly as stated.

(4) With the *supply voltage  $V$  and frequency  $f$  each kept constant* at the normal value for the motor  $M$ , and with the *excitation ( $a_f$ ) kept constant* at the value noted in obs. 3 (namely that giving minimum armature current  $A$ ), take a series of brake loads on  $M$  rising by about equal amounts up to about 25% over load, noting the readings of  $V$ ,  $W$ ,  $a_f$ ,  $A$  speed, and output factors at each load.

**Note.**—As the heating of a machine is the factor limiting the maximum safe output, it is desirable to estimate the brake loading by roughly equal amounts of main current  $A$  up to about 25%, or even 50%, over load if kept on only a few minutes, calculating and taking the B.H.P. corresponding to such current values. The method of loading the motor  $M$  may be that indicated in the Note, obs. 5, test No. 106.

(5) Repeat obs. 4 for two or three higher—and two or three lower—*constant* values of excitation ( $a_f$ ) than that used in obs. 4 above, which gave minimum value of  $A$ , and tabulate as per schedule shown on page 308, but adding one extra column for efficiency  $\left( = \frac{\text{B.H.P. output}}{\text{E.I.P. absorbed}} \right)$  of  $M$  at each load.

(6) Plot the following curves, namely, having in every case B.H.P. outputs as abscissae with (1) efficiency, (2) amperes  $A$ , (3) watts  $W$ , or E.I.P. absorbed, and (4)  $\cos \phi$ , as ordinates respectively.

**Inferences.**—From a careful study of the figures and also of the shape and relative dispositions of the curves, state what can be deduced.

### Relations between the Supply Factors of an Alternating Current and the Constants of the Circuits supplied.

**General Remarks.**—Every electrical circuit possesses three distinct qualities, namely—

(i) Electrical—or ohmic resistance, depending on the length, sectional area and material of which it is made.

(ii) Electrical—or electrostatic capacity, depending on the length, surface, form and the specific inductive capacity of the surrounding dielectric.

(iii) Electrical—or self-inductance, depending on the shape, form and magnetic permeability of the surrounding conducting material.

All of these qualities are always present in every circuit whatsoever, but it may happen that one or more of them are so small as to be negligible from a practical point of view. Thus we are accustomed to speak of some special circuit as possessing *only* one of them, any two, or all three of them at once. It is often of the utmost importance to know the nature of a circuit, with reference to the above qualities, when alternating currents are employed, for the presence of one or more of them in such a circuit may be very troublesome or may be a necessity according to circumstances. Theory dictates that variation in the periodicity of the alternating supply causes, in some cases, a considerable change in the working results of a circuit, and it is with a view to clearly elucidating the effects of variation of frequency on circuits in which one or more of these qualities predominate that the following tests have been devised, and also of determining how such variations affect the power absorbed in the circuit, and also the corresponding variation of temperature (if any). In all cases the power is to be measured by a *Wattmeter* as nearly *non-inductive* as it is possible to have it, for it will then give a *true* measure of the power absorbed. The results to be expected, as dictated by theoretical considerations, are as follows—

Let  $A = \sqrt{\text{mean sq.}}$  value of current in amperes flowing in the circuit.

$V = \sqrt{\text{mean sq.}}$  „ „ voltage acting on the circuit.

$R =$  ohmic resistance of the circuit.

$L =$  its self-induction in henries.

$C =$  its electrostatic capacity in farads or  $C \times 10^6$  microfarads.

$p =$  the angular velocity of the alternating supply  $= 2\pi \times$  frequency.

Then we have for circuit possessing—

$$\text{R only :—} A = \frac{V}{R}$$

and the current is in phase with the voltage.

$$\text{R and L only (in series) :—} A = \frac{V}{\sqrt{(Lp)^2 + R^2}}$$

the current now *lagging* in phase behind the voltage by an angle  $\theta$  such that  $\tan. \theta = \frac{Lp}{R}$ .

$$\text{R and C only (in series) :—} A = \frac{V}{\sqrt{\left(\frac{1}{Cp}\right)^2 + R^2}}$$

the current now *leading* in phase in advance of the voltage by an angle  $\theta$  such that  $\tan. \theta = \frac{1}{CpR}$ .

$$\text{R, L, and C (in series) :—} A = \frac{V}{\sqrt{\left(Lp - \frac{1}{Cp}\right)^2 + R^2}}$$

where  $L$  predominates over  $C$ , the current now *lagging* in phase

behind the voltage by an angle  $\theta$  such that  $\tan. \theta = \frac{Lp - \frac{1}{Cp}}{R}$ .

where  $C$  predominates over  $L$ , the current leads in phase in front of the voltage by an angle  $\theta$  and the last two relations become—

$$A = \frac{V}{\sqrt{\left(\frac{1}{Cp} - Lp\right)^2 + R^2}} \quad \text{and} \quad \tan \theta = \frac{\frac{1}{Cp} - Lp}{R}$$

$$C \text{ (only)} :- A = \frac{V}{\frac{1}{Cp}} = CpV,$$

the current now being  $90^\circ$  in phase in advance of the voltage.

$$L \text{ (only)} :- A = \frac{V}{Lp},$$

the current lagging  $90^\circ$  in phase behind the voltage.

$$\frac{V}{A} = \text{Impedie Resistance.}$$

The radical denominators in the three expressions for  $A$  are termed the *apparent* or *effective resistances* of the circuit containing those particular qualities, though one of these, namely  $\sqrt{L^2p^2 + R^2}$ , is very generally termed the *impedance* of the circuit. The terms  $Lp$ ,  $\frac{1}{Cp}$ , and  $(Lp - \frac{1}{Cp})$  are called the *reactances* or *reactive resistances* of the circuit, and when multiplied by the current give the reactance voltage. The phase relations are shown by the vector diagram  $OBD$ , Fig. 108, and

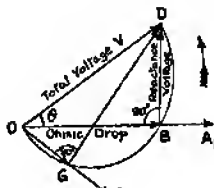


FIG. 108.

if each voltage is  $\div$  by the current we shall get a proportionate *Scalar* diagram (i.e. without arrows) in which  $OD$  = apparent resistance,  $OB$  = ohmic resistance, and  $BD$  = reactance or inductive resistance, while  $OA$  = the current. It will now be obvious that if the ohmic resistance is extremely small (for it cannot be zero) the impedance becomes = the reactance, but when the ohmic resistance is large, the impedance is affected by it considerably. Again, since the term for reactance contains  $p = 2\pi \times \text{frequency}$ , it is directly  $\propto$  to frequency, while ohmic resistance is independent of frequency.

Further, impedance depends on the remaining component factor, namely, self-induction, which latter in most cases is due to a coiled circuit surrounding iron. Now, the self-induction of a circuit depends on the linkage of turns with magnetic field, increasing directly with the latter and with the square of the former. Thus it depends on the current, which in turn decides the degree of magnetic saturation of the core. The self-induction of the armature of an alternator is really only an average of several values obtained for different positions of the armature coils relatively to the field poles, and it affects the "wave form" of the voltage generated. Since the self-induction  $L$  is directly  $\propto$  to the mean permeability ( $\mu$ ) of the magnetic circuit, it follows that in cases where  $R$  is small compared with the  $L\rho$ , the impedance will vary nearly in direct proportion to  $\mu$ , consequently a curve between impedance and current will approximate to the orthodox permeability curve of the core.

On the other hand, with a low resistance winding, the voltage absorbed in it, due to the term  $AR$ , is so small that the voltage at the terminals is practically that due to self-induction only, and hence directly  $\propto$  to the core flux. Thus a curve between terminal voltage and current will have the shape of that part of the magnetization curve between the origin and "knee," the higher parts of the curve being absent owing to the low degree of magnetic saturation used in the cores of A.C. plant.

Turning now to considerations relative to capacity, the fundamental definition of an electrical condenser being that of two conductors (called the coatings), separated by an insulator (called the dielectric), it follows that on connecting the coatings to a source of E.M.F., positive and negative quantities of electricity will flow on to them in raising them to the same difference of potential as that of the source. The attraction between these two quantities sets up a corresponding stress in the dielectric and causes them to remain "bound" after the charging source is removed. The charge of the condenser is measured in coulombs, and is the quantity  $Q$  (which = the current in amps  $\times$  time of flow in seconds) necessary to raise the voltage between the coatings to the value  $V$  of the source. Thus, if  $C$  denotes the capacity of the condenser, we have  $Q = CV$ , or the capacity  $C = \frac{Q}{V}$  = a constant for any condenser and for all charging

currents as distinguished from the self-induction of a coiled circuit which is not constant, when containing magnetic material, but varies with the magnetic saturation of the core, and hence with the current. If the source of E.M.F. is an alternating one, the state of charge of the condenser will follow exactly the change of voltage, reaching a + " and - " maximum, each once in every period of the supply. While, therefore, the current flowing in an A.C. circuit containing a condenser is actually a *charge and discharge current alternately*, and does not flow continuously through, owing to the impassable dielectric insulation, an A.C. ammeter placed in the same circuit, by its steady reading and inability to follow the rapid pulsations of current, makes it appear as if the current really passed *through* the condenser, though it does not do so.

Again, the internal or ohmic resistance of a self-inductance affects the corresponding impedance, while the internal resistance of a given condenser has no such effect on the corresponding impedance. From the relation already given for the current in amperes  $I = C_p V \div 10^6$ , where  $C_p$  = the capacity in micro-farads and  $V$  = terminal pressure in volts, it will be seen that at the smaller pressures of 100 volts or so at about 50 ~ per sec., a considerable value of ( $I$ ) will be needed to give an appreciable current. Since, therefore, the capacity available is usually well under 110 mfd.s, only a small current will result. In this case, care should be taken that the voltmeter used does not affect the voltage across the points between which it is applied, a condition fulfilled by the use of an electrostatic voltmeter.

The tests which immediately follow are arranged to show the variation of the quantities indicated with the factors composing them, only one of which must be varied at a time in order to test its influence on the main quantity.

### (108) Determination of whether a Resistance is truly Non-Inductive at any Frequency and Current.

**Introduction.**—As in nearly all laboratories there is usually a shortage of rheostats, more particularly those of a non-induc-



tive nature, which are essential in the majority of A.C. tests, the present determination is both instructive and useful.

It is obvious that any inductive resistance must possess *some* ohmic resistance, while a so-called ohmic resistance usually exhibits *some* slight inductiveness. Carbon plate, liquid and glow-lamp rheostats are usually taken to be non-inductive for all practical purposes, which they are, especially the two first named. Since carbon filament lamps are usually employed in lamp rheostats in pure parallel combinations, the inductiveness of one lamp with its filament of one or more turns is finite though very small, and hence that of any combination is still smaller and practically nil.

Liquid rheostats usually consist of two or more metal plates dipping into a container of water, the conductivity of which is increased to any desired extent by the addition of a little common washing soda or aluminium sulphate. Such rheostats are undoubtedly less convenient than the carbon or lamp types, because, although electrolytic action with A.C. is negligible, they froth and alter in resistance considerably with rise of temperature, due to the absorption of the power in them.

Wire-wound rheostats, whether composed of wire spirals wound in a continuous spiral or non-inductively, are usually prominent in most test rooms. How far such rheostats, whether wound with high-resistance alloys (usually non-magnetic) or with iron (which is highly magnetic) are non-inductive, is the object of the present investigation. With the former, the self-induction would be constant for all current densities, but would vary with the frequency. Further, the effective or apparent resistance increases for increase of cross-sectional area of wire with alternating current, and the self-induction varies as the (number of turns)<sup>2</sup>  $\times$  sectional area of spiral  $\div$  length of spiral.

**Apparatus.**—Alternator *D*, capable of being driven at a wide range of speeds, so as to obtain a corresponding range of frequency at constant voltage *V* by varying the exciting circuit (not shown); Siemens electro dynamometer, hot wire or other A.C. ammeter *A* unaffected by frequency; electrostatic voltmeter *V*; non-inductive wattmeter *W*; switch *S*, and resistance *R* to be tested.

**Observations.**—(1) Connect as in Fig. 109, and adjust all the

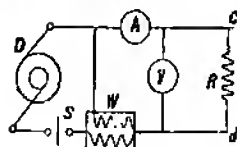


FIG. 109.

instruments to zero. Then start *D*, seeing that the lubricating arrangements feed properly.

(2) By field regulation adjust the voltage *V* across the terminals of *R*, that a convenient current flows through it as indicated by *A*.

(3) Obtain about ten or twelve different speeds of *H* from the smallest to the largest practicable and safe, varying the excitation so as to keep *A* constant throughout. Note simultaneously the readings of *A*, *V*, *W* and speed.

(4) With the speed, and hence the frequency adjusted to some convenient value to be kept constant, vary the voltage by field regulation so as to obtain 8 or 10 different currents through *R* between 0 and maximum safe value, noting the readings of *A*, *V*, *W*, and speed at each, and tabulate your results as follows—

NAME . . .

DATE . . .

Alternator: Periods per Revolution *K* = . . .Resistance *R* = . . . ohms.Constants: Wattmeter = . . . and *A* = . . .Nature of Resistance *R* = . . .

Speed Rat. per min. ( <i>N</i> )	Frequency per sec. $\frac{KN}{60}$ ( <i>F</i> )	Volts <i>V</i>	Watts Reading of <i>W</i>	Amperes <i>I</i> $\frac{W}{V}$	True Watts $\frac{VI}{\cos \theta}$ $= K_1 P$	Apparent Watts $\frac{VI}{\cos \theta}$ $= K_2 P$	$\cos \theta$ $\frac{P}{VI}$	$\frac{P}{VI}$ $= \frac{1}{K_1}$	$\frac{P}{VI}$ $= \frac{1}{K_2}$

(5) Plot curves having values of *F* and  $\cos \theta$  as abscissae in each case, and *V*,  $\cos \theta$ , and  $\frac{V}{\cos \theta}$  as ordinates.

**Inferences.**—State clearly all that you can deduce from your experimental results and your curves.

## (109) Measurement of Power Factor in Alternating Current Circuits.

**Introduction.**—Alternating-current ammeters and voltmeters measure the mean or average value of the current or voltage in

an A.C. circuit, and the product of their readings is, therefore, the product of two mean values. If the circuit is non-inductive, this product of the mean or average values is the *true mean* or average value of the power in watts given to the circuit. If the circuit is inductive and possesses self-induction or capacity or both, the above product does not give the true mean power, but only what is commonly called the volt-amperes of *apparent power* in watts. The true mean or average power in this case is given by the mean or average value of the product (amperes  $\times$  volts) in the circuit, for *the mean product of two periodic functions representing current and pressure is not equal to the product of their mean values.*

Now, the mean value of the product, which thus represents the *true power* in watts, can be measured directly by a wattmeter, and the ratio

$$\frac{\text{true power in watts}}{\text{apparent power in watts}} = \frac{\text{wattmeter reading}}{\text{amps.} \times \text{volts}}$$

is called the *power factor* of the circuit, which in practice can vary only between the two extreme values 0 and 1.

This limiting variation, together with the difference observed between the true and apparent power in watts in an inductive circuit, is explained by the fact that the current and voltage in such a circuit are not in phase, as will be understood by a reference to the so-called vector diagram (Fig. 110). Let the voltmeter reading be represented in magnitude (on some convenient scale) by the length of a straight line  $OV$  and the direction of action of the pressure or voltage by the arrow head, *i. e.* from  $O$  to  $V$ .

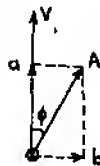


FIG. 110.

Thus  $OV$  is the voltage vector. Similarly let  $OA$  be the current vector for the ammeter reading, differing in phase from  $OV$  by an angle  $\phi$ .

Now  $OA$  can be resolved into two component currents at right angles to one another—the one  $Oa$  in line with  $OV$ , the other ( $Ob$ ) at right angles to it. Then  $Oa$  is called the useful energy- or *load-current*, and  $Ob$  the useless, idle-, or *wattless-current*, connected solely with the periodic charge and discharge of energy in the circuit due to its inductance.  $OaA$  is therefore

a triangle of currents for the inductive circuit in which  $OA$  is the resultant (or ammeter current) of two other currents, namely, an energy current  $Oa$  and an idle current  $aA$  always differing in phase by  $90^\circ$ . Then the product of the ammeter and voltmeter readings  $= OA \times OV =$  the apparent watts, the wattmeter will give a reading  $= OV \times Oa =$  the true, or useful, watts, while the wattless power will be given by  $OV \times Ob$  watts, which does no work in the circuit.

Thus from the geometry of the figure we have the ratio

$$\frac{\text{true watts}}{\text{apparent watts}} = \frac{OV \times Oa}{OV \times OA} = \frac{Oa}{OA}$$

$= \cos \phi =$  the power factor of the circuit.

Although obtainable in other ways (vide p. 331), this ammeter, voltmeter, wattmeter method is by far the best and most direct one for measuring power factor, and is almost invariably employed.

The evaluation of the power factor  $\cos \phi$  in the case of single-, two-, and three-phase A.C. inductive circuits, by this direct method, is given on p. 338 *et seq.*, and in the following test we shall restrict ourselves to single-phase circuits.

**Apparatus.**—Precisely that detailed for test No. 111.

**Observations.**—(1) Connect up as in Fig. 112, levelling and adjusting to zero such instruments as need it. The extremities  $T_1, T_2$  of the combination of  $C$  and  $r$  are the terminals of the circuit of which the power factor (P.F.) is required. As, however, it is sometimes necessary in A.C. testing work to obtain either an electrical load at varying P.F. or a variable load at constant P.F. with a choker and resistance, it is both useful and instructive to determine the effect on the value of the P.F. of changing (A) the ohmic resistance, (B) the inductance (whether by change in current strength or in disposition of magnetic circuit), and (C) the frequency—one at a time.

(3) A.—Note the readings of all the instruments, for each position of the two-way key  $K$ , for some eight different values of  $(v)$ —the frequency  $F$  and current  $A$  being kept constant throughout.

(3) B.—Note the readings of all the instruments, for each position of the two-way key  $K$ , for some eight different values of current  $A$ , covering the range of current utility of the circuit

or appliance in use—the frequency  $F$  and resistance  $r$  being kept constant throughout.

(4) C.—Note the readings of all the instruments for each position of the two-way key  $K_1$  for some eight different values of frequency  $F$ —the resistance  $r$  and current being kept constant throughout.

Tabulate all your results as follows—

Coil (C):—Length = . . . No. of turns = . . . Resistance ( $R$ ) = . . . ohms  
 Core: Length = . . . Sections = . . .  
 Non-inductive Resistance ( $r$ ):—Value . . .

Ohmic Resistance		For Inductive Circuit XZ				For Non-inductive Circuit XY			
Non-inductive $r = \frac{V}{A}$	Total $Rr = R + r$	Current $A$	Frequency $F$	Volts $E$	Apparent Watts $EA$	True Watts $W$	Power Factor $\cos \phi = \frac{W}{EA}$	Volts $E$	Apparent Watts $EA$

(5) Plot curves having values of power factor  $\frac{W}{EA}$  as ordinates, with values of  $Rr$  in obs. 2; current  $A$  in obs. 3; and frequency  $F$  in obs. 4—respectively as abscissae in each case.

**Inferences.**—State clearly all that can be deduced from the tables of results and the curves.

### (110) Determination of the Effect of Frequency on the temperature of a given Circuit containing *Self-Induction and Ohmic Resistance only.*

**Introduction.**—The present test is devised with a view to ascertaining whether change of frequency materially alters the temperature of any appliance possessing self-induction and ohmic resistance, and for the success of the investigation the coils of the appliance used should have a low ohmic resistance, so that transference of heat due to the term  $C^2R$  to the core in which any alteration of temperature is to be observed, may be as small as possible.

**Apparatus.**—Alternator *D* capable of having its speed varied

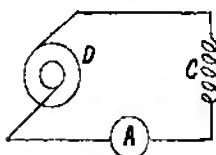


FIG. 111.

between wide limits, and whose voltage can be regulated by the exciting circuit (not shown); ammeter *A* (Fig. 251); hollow solenoid *C* to test, having a bundle of fine soft iron wires, smaller than the internal hollow, to allow of a thermometer being inserted as well as the bundle.

**Observations.**—(1) Connect up as in Fig. 111, and insert the core and thermometer in the solenoid, covering up the ends with cotton wool to prevent external cooling effects due to the air, etc. Note the temperature when steady.

(2) Adjust the speed and excitation of *D* so that the frequency has the lowest value practicable, and the current *A* some convenient value not high enough to heat the coils much.

(3) The speed and current *A* being kept constant, take the temperature *T*° on the thermometer at successive noted intervals of time (*t*) from switching on until it remains constant, and note also the temperature of the room at intervals.

(4) Repeat 2 and 3 for the maximum speed allowable, and for one intermediate between this and the first-mentioned, the core having been allowed to cool down in between each distinct set of observations, and the current *A* being the same. Tabulate your results as follows—

Name . . .

Date . . .

Nature of Coil tested . . .

Form of Core . . .

Periods of alternator per Revol.  $F = \dots$ 

Temperature of Room.	Temperature of Core for start $T^\circ \text{C.}$	Time from start $t$ .	Speed Revs. per min. $N$ .	Frequency $\sim$ per sec. $= \frac{FN}{60}$

(5) Plot a curve for each frequency on the same sheet, having temperatures  $T^\circ \text{C.}$  as ordinates, and (*t*) minutes as abscissae.

**Inferences.**—What can you infer from your experimental results and the curves?

(III) Variation of Impedance with (a) Self-Induction, (b) Frequency, and (c) Ohmic Resistance in Circuits having Self-Induction and Ohmic Resistance only in Series.

**Introduction.**—In this test it will be necessary to vary one factor only at a time, keeping the remaining two constant. It should also be remembered that, as the coefficient of self-induction of any coiled circuit is the number of lines of force linked with it when unit current flows through it, any change in the current will alter the permeability of the magnetic path when this is composed partly or wholly of magnetic material, and hence also the self-induction. With an air-core the self-

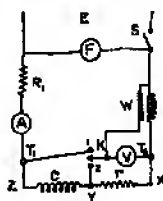


FIG. 112.

induction will be constant for all values of current. The variation of impedance and self-induction of an iron-cored solenoid with the position of the core has already been investigated in test No. 118, and the present determination can be conveniently made for fixed positions of the core *P* (Fig. 123).

**Apparatus.**—Source of A.C. supply *E*, preferably a motor-driven alternator; the excitation and speed of which are independently variable within wide limits; switch *S*; frequency meter *F*; ammeter *A*; voltmeter *V*; wattmeter *W*; two-way key *K*; two non-inductive variable rheostats *R*<sub>1</sub> and *r* (e.g. banks of lamps or carbon-plate rheostats); solenoidal choker *C* with movable iron core.

**Note.**—*R*<sub>1</sub> is needed (only if the supply *E* is from town mains) for keeping the current *A* constant, as *r* is varied. *T*<sub>1</sub>*T*<sub>2</sub> are to be taken as the terminals of the impedance.

**Observations.**—(a) *Impedance with Self-induction at Constant Frequency and Ohmic Resistance.*

(1) Connect up as in Fig. 113, levelling and adjusting such instruments to zero as need it. Start the alternator with field regulator "full in," and see that the lubricating arrangements are working properly.

**Note.**—The following tests, Nos. 2 and 3, can be made on a public A.C. supply instead, if desired.

(2) With the core  $P$  clamped centrally in the coil  $C$ , and the speed adjusted to give a frequency  $f$  (= no. pairs of poles  $\times$  revs. per min.  $\div 60$ ) of 50  $\sim$  per sec., close  $S$ , and by field regulation obtain some eight different currents on  $A$ , rising by about equal increments from 0 to the maximum safe value for the coil  $C$ , and note the readings of  $F$ ,  $A$ ,  $W$  and  $V$  at each, the frequency  $f$  and resistance  $r$  being constant throughout.

(3) Readjust the field regulator to "full in," and with the core  $P$  removed altogether, repeat 2 for the same constant frequency and range of currents.

(b) *Impedance with Frequency for Constant Self-induction and Ohmic Resistance.*

(4) Fulfil obs. 1 above; a variable speed alternator now being a necessity.

(5) With  $P$  clamped centrally, adjust the speed and consequently the frequency  $f$  to the lowest convenient value, and the current  $A$  (by field regulation) to, say, half the maximum value for the coil, to avoid much change of ohmic resistance by heating. Note the readings of  $F$ ,  $A$ ,  $W$  and  $V$  at each of some eight different values of  $f$  between the lowest and highest convenient, obtained by speed regulations, the above value of current  $A$  being kept constant throughout by field regulation.

(6) Repeat 5 with the core removed altogether, and for the same constant current, and tabulate all the results of obs. 2 to 6, as shown.

(c) *Impedance with Ohmic Resistance for constant Self-induction and Frequency.*

(7) With the core of  $C$  clamped centrally and a constant frequency  $f$  of, say, 50  $\sim$  per sec. adjust the current  $A$  to about half the maximum safe value for  $C$  (to minimize heating) and keep it constant throughout (by varying  $R$ , with town



supply for  $E$  or by field regulation with an experimental alternator for  $E$ ) for some eight different values of  $r$  between 0 and the highest convenient, noting at each the readings of  $F$ ,  $A$ ,  $W$  and  $V$ , when the latter is connected by  $K$  across  $T_1$ ,  $T_2$  and  $r$  respectively.

(8) Repeat (7) with the core of  $G$  removed altogether for the same current and frequency, and tabulate as follows—

Coil ( $C$ ): Length = . . . No. of turns = . . . Resistance ( $R$ ) = ohms.  
 Core. Length = . . . Section = . . .  
 Non-inductive Resistance ( $r$ ): Nature . . .  $p = 2\pi F = \dots$

Frequency $F$	Angle $A$	Position of Core of Choke $C$	Voltage across Impedance $V_p$	Non-inductive Resistance $r$	Impedance $Z_p = \sqrt{L^2 p^2 + R^2}$	Ohmic Resistance $R$	Total $Z_t = \sqrt{L^2 p^2 + R^2 + r^2}$	Watmeter Reading across $T_1 T_2$	Total True Watts $W$ in shunt with $A$ and $V$	Power Factor $\cos \theta = \frac{W}{V I}$	Angle of Lag $\theta$	Maximum $\frac{W}{V I} = \sqrt{\left(\frac{V}{Z_t}\right)^2 - R^2}$	Coefficient of Self Induction $\frac{L}{Z_t} = \frac{1}{p} \sqrt{\left(\frac{V}{Z_t}\right)^2 - R^2}$
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(9) From obs. 2 and 3 plot curves having values of impedance, as ordinates, with values of  $A$ ,  $L$ , and  $Lp$  as abscissae in each case; also between  $V$  and  $L$  as ordinates and  $A$  as abscissae.

From obs. 5 and 6 plot curves having values of impedance, as ordinates, with values of  $F$  and ( $Lp$ ) as abscissae.

From obs. 7 and 8 plot curves between impedance as ordinates and  $R_r$  as abscissae.

**Inferences.**—From a careful study of the tables of results and forms of curves state clearly all that can be inferred therefrom.

## (112) Numerical and Phase Relations between the Voltages and between Voltage and Current in Circuits containing Capacity only and when in Series with Ohmic Resistance.

**Introduction.**—The numerical relations between the various voltages in a circuit such as is now under consideration, seem at first sight to be so impossible that it is necessary to consider them in relation to phase. This can be done by a reference to the vector diagram (Fig. 113). In this, the total or resultant

voltage, as indicated on the ammeter  $A$ , is set off in magnitude and direction  $= OD$ . The energy voltage or ohmic drop  $OG$  is set off at an angle  $\phi_1$  in advance of  $OD$ , while  $GD$  will be the condenser, idle, or reactive voltage in magnitude and direction.

Comparing this with Fig. 108 for a self-inductive circuit, we see that capacity causes the current and its vector  $OA_1$  to lead in front of the voltage  $OD$  by an angle  $\phi_1$ , instead of to lag behind as shown in Fig. 108 for self-inductive circuits, both diagrams being supposed to rotate about  $O$  in the  $+$  direction (counter-clockwise). The angles  $B$  and  $C$  being right angles, lie (by geometry) on a semicircle, which is consequently the loci of the point of intersection of the energy and reactive voltages (which always differ by  $90^\circ$  in phase) between their limiting

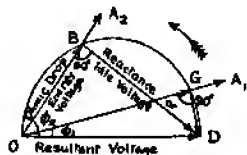


FIG. 118.

values of resistance  $R$  and capacity  $C$  respectively, namely, that of  $R = \text{maximum}$  with  $C = 0$ , for which  $\phi_1 = 0$ ,  $OG = OD$ , and  $GD = 0$ ; and that of  $R = 0$  with  $C = \text{maximum}$ , for which  $\phi_1 = 90^\circ$ ,  $GD = OD$ , and  $OG = 0$ . If for the triangle of voltages  $OGD$  we divide each of the voltages by the current  $A_1$ , the sides will represent the corresponding resistances in circuit, while the voltage vectors, as given if divided by these resistances respectively, will give the triangle of currents. The idle or wattless current equals  $A_1 \sin \phi_1$ , and the energy current equals  $A_1 \cos \phi_1$ .

**Apparatus.**—Source of A.C. supply  $E$  of, say, constant frequency, such as town mains; switch  $S$ ; variable non-inductive resistances  $r$  and  $R$ ; ammeter  $A$ ; electrostatic voltmeter  $V$ ; two two-way keys  $K_1 K_2$ ; condenser  $C$ .

**Observations.**—(1) Connect up as in Fig. 114, levelling and adjusting to zero  $A$  and  $V$ , if necessary.

(2) With  $R$  adjusted to 0 close  $S$ , and by varying  $R$  obtain

some six or eight values of current  $A$ , rising by about equal increments from 0 to the maximum possible, noting the values of  $V_1$ ,  $V_2$ , and  $V_3$  on  $V$  by means of  $K_1$  and  $K_2$ .

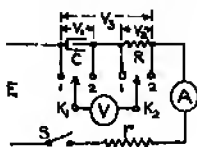


Fig. 114.

**Note.**—A convenient form of non-inductive resistance to use for  $R$  would be an 8 C.P., 16 C.P., and 32 C.P. glow-lamp, each of the same voltage as that of the supply, and arranged so as to be paralleled in any combination, thus giving seven possible different resistances of wide range. Tabulate your results as follows—

Capacity used: Type and Maker . . . Value = . . . mfd.  
Non-ind. Res. used: Nature . . . Frequency (constant)  $f$  = . . . ~ per sec.

Voltage across			Amps. $A$	Ohmic Resistance $R = \frac{V_2}{A}$	Impedance $\frac{V_1}{A}$	Power Factor $\cos \phi = \frac{V_2}{V_1}$	Angle of lead $\phi$
Supply $V_2$	Capacitor = Idle volts ( $A$ and $C$ ) $V_1$	Non-inductive Resistance = empty ( $A$ ) $V_2$					

(3) Plot curves having values of  $V_1$  as ordinates, with  $V_2$  and  $C$  as abscissae respectively. Also between  $\cos \phi$  and impedance, as ordinates, with values of  $R$  as abscissae. Compare  $V_3$  with the algebraical sum ( $V_1 + V_2$ ).

**Inferences.**—State clearly all that can be deduced from your results.

(113) Variation of Impedance with (a) Capacity, (b) Frequency, and (c) Ohmic Resistance in Circuits having Capacity and Ohmic Resistance only in Series.

**Introduction.**—While the term impedance is applied almost universally to denote the apparent resistance of an alternating current circuit containing self-induction and ohmic resistance only, it is also used here to denote the expression  $\sqrt{1/C^2p^2 + R^2}$  for the apparent resistance of an A.C. circuit having capacity ( $C$ ) and ohmic resistance ( $R$ ) only, the angular velocity  $p$  of the current being  $= 2\pi \times$  frequency. As therefore it contains three variable factors, it will be necessary to vary one only at a time, keeping the remaining two constant.

When  $C$  and  $p$  are respectively the variables, we may make  $R = 0$  and determine the effect of each on the remaining term,  $\sqrt{\frac{1}{C^2p^2}} = \frac{1}{Cp}$ , called the reactance or reactive resistance of the circuit.

**Apparatus.**—Source  $N$  of A.C. supply, preferably a motor-driven alternator, the speed and voltage of which can be varied

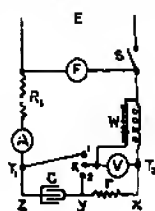


FIG. 115.

within wide limits; ammeter  $A$ ; voltmeter  $V$ ; wattmeter  $W$ ; frequency meter  $F$ ; switch  $S$ ; variable capacity  $C$ ; variable non-inductive resistance  $r$ ; two-way key  $K$ ; variable non-inductive rheostat  $R_1$  (only needed if  $N$  is town mains).

**Observations.**—(a) Impedance with Capacity at Constant Frequency and Ohmic Resistance.

(1) Connect up as in Fig. 115, levelling and adjusting to zero such instruments as need it. Start the alternator with field regulator "full in," and see that all lubricating arrangements in use are working properly.

(2) With the alternator up to maximum speed, and therefore giving maximum frequency  $F$  ( $=$  No. of pairs of poles  $\times$  rev. per min.  $\div 60$ ), close  $S$ , and adjust  $C$  to some six or eight different capacities, rising by about equal increments from the smallest to largest available, noting the reading of  $F$ ,  $A$ ,  $C$  and of  $W$  and  $V$  on  $K_2$  at constant frequency  $F$  and resistance ( $r$ ).

(3) With  $r = 0$  repeat obs. 2 for the same values of  $C$ , noting  $W$  and  $V$  on  $K_1$ , in addition to  $F$ ,  $A$ ,  $C$ , for the same constant frequency.

(b) *Impedance with Frequency for Constant Capacity and Ohmic Resistance.*

(4) A variable speed alternator being available, make  $C$  a maximum and give  $r$  some convenient fixed value. Now read all the instruments for both positions of  $K$  at each of some six or eight frequencies differing by about equal amounts between the maximum and minimum values obtainable by speed regulation.

(5) With  $r = 0$  repeat obs. 4 for the same constant value of  $C$  and range of frequencies.

(c) *Impedance with Ohmic Resistance for Constant Capacity and Frequency.*

(6) Give  $C$  and the frequency their maximum possible values, and take the readings of all the instruments with  $K$  on studs 1 and 2 for some six or eight values of  $r$ , differing by about equal amounts between maximum and zero values.

Tabulate all your results as follows (where  $p = 2\pi f$ )—

Frequency $f$ .	Amph. $A$ .	Capacity $C$ .	Volts across impedance $V_1 V_2 = V_p$	Volts across non-ind. Res. $r = F_r$	Ohmic Res. $r$ .	Impedance $V_1 V_2$ ohms $= \sqrt{V_1^2 V_2^2 + r^2}$	Resistance 1/2p ohms.	Wattmeter across $F_1 F_2 = W_p$ Watts.	Wattmeter across $r = W_r$ Watts.	Watts absorbed in $r = \Delta P_r$	Apparent Watts $= \Delta P$	Power Factor $\cos \phi = W_p / \Delta P$	Angle of Lag $\phi$ .
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(7) From obs. 2 and 3 plot curves having values of impedance  $\left(\frac{V_I}{A}\right)$ , reactance  $\frac{1}{C_p}$  and amps.  $A$  as ordinates with values of capacity  $C$  as abscissae.

From obs. 4 and 5 plot  $\frac{V_I}{A}$ ,  $\frac{1}{C_p}$  and  $A$  as ordinates with frequency ( $f$ ) as abscissae, and from obs. 6 plot  $\frac{V_I}{A}$  as ordinates with ohmic resistance ( $r$ ) as abscissae.

**Inferences.**—State clearly all that can be deduced from the above results.

#### (114) Variation of Impedance with (a) Self-induction, (b) Capacity, (c) Ohmic Resistance, (d) Frequency in Circuits having Characteristics $a$ , $b$ and $c$ in Series.

**Introduction.**—It has been stated that self-induction  $L$  causes the current to lag behind the voltage, while capacity  $C$  causes it to lead in front of the voltage. A circuit possessing both  $L$  and  $C$  may therefore cause the current to lag behind, lead in front of, or be in phase with, the voltage, depending on the relative mag-

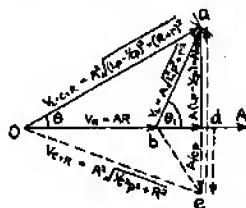


FIG. 116.

nitudes of  $L$  and  $C$  for a given ohmic resistance and frequency. Each of the two last named will in turn affect such phase relations, and hence in the present investigation we have four possible variables composing the impedance or "apparent" resistance of the circuit, only one of which must be varied at a time with the remaining three kept constant.

The phase difference between current and voltage will be less than that which would be caused by the same value of either  $L$  or  $C$  alone, and, as stated above, may even be zero. The above remarks will be better understood by a reference to Figs. 116 and 117.

Let  $OA$  be a vector representing, in magnitude and direction, the current  $A$ . Set off  $Ob =$  the voltage  $V_R (= AR)$ , which is an energy or useful voltage in phase with  $A$ , along  $OA$ .

With centre ( $b$ ) and radius  $ba = V_L$  describe an arc of a circle, and with centre ( $O$ ) and radius  $Oa = V_{L+R}$  describe an arc

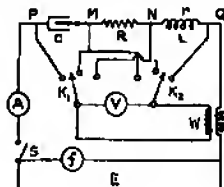


FIG. 117.

of a circle (Fig. 116), intersecting the other arc in the point ( $a$ ).

From ( $a$ ) drop a perpendicular to  $OA$  meeting it in ( $d$ ) and produce it to ( $e$ ) so that  $de = V_e = \frac{A}{C_p}$  the condenser voltage.

This will be  $180^\circ$  out of phase, i. e. in direct opposition to the voltage overcoming the self-induced idle voltage ( $ea$ ) =  $LpA$ . Consequently the nett or effective idle voltage of the circuit

$da = A \left( Lp - \frac{1}{C_p} \right) = AL_1p$ , where  $L_1$  = the effective or nett inductance of the whole circuit  $PQ$ , and is of a self-inductive nature causing an effective angle of lag  $\theta$  in the circuit. In the triangle  $Ode$ ,  $Ar = O$ , since the condenser  $C$  is not considered to have any ohmic resistance  $r$  like the self-inductance  $L$  has. Therefore  $Od$  = the energy voltage  $AK$  for the portion  $PN$ ,  $Od$  is therefore also the useful or load component of the total voltage of the circuit  $PQ$ .

A most important deduction, affecting the calculation of the rise of pressure in cables and sometimes the breakdown of their insulation, now follows, namely, if the reactances of the self-

inductive and capacity portions are equal, i.e. if  $Lp = \frac{1}{Cp}$  where  $p = 2\pi f$  and  $f =$  the supply frequency, the idle voltages of  $L$  and  $C$  will be equal and opposite in sign, and each may have much greater values than that of the supply. This condition in such a series combination, shown in Fig. 117, is called *pressure resonance*.

The above condition may be written  $2\pi fL = \frac{1}{2\pi fC}$ , from which we

get  $f = \frac{1}{2\pi\sqrt{LC}} \sim$  per sec., but only when the ohmic resistance

of the circuit is negligible is the periodicity of the supply equal to the *natural* periodicity of oscillation. The natural period of the

circuit  $\frac{1}{f} = 2\pi\sqrt{LC}$  seconds. The periodicity giving maximum

resonance in a circuit of appreciable ohmic resistance  $R$  is

$f = \frac{1}{2\pi\sqrt{LC - \frac{R^2}{4L^2}}}$  which is not the *natural* periodicity of oscillation of the circuit.

Either of the above values of the critical frequency ( $f$ ) giving maximum resonance is usually much greater than that of the supply voltage.

**Apparatus.**—Source of A.C. supply  $E$ , preferably a motor-driven alternator having a wide range of speed and excitation; ammeter  $A$ ; wattmeter  $W$ ; switch  $S$ ; voltmeter  $V$ ; and two three-way keys; a capacity  $C$ , self-induction  $L$ , and ohmic resistance  $R$ , each capable of variation; frequency meter ( $f$ ).

**Observations.**—(a) *Impedance with Self-induction at Constant Frequency, Capacity and Resistance.*

(1) Connect up as in Fig. 117, levelling and adjusting to zero such instruments as need it. Start the alternator with field regulator "full in," and see that the lubricating arrangements are working properly.

(2) With the self-induction  $L$ , resistance  $R$ , and capacity  $C$  adjusted to convenient values, and the speed to give a frequency  $F$  ( $=$  No. of pairs of poles  $\times$  rev. per min.  $\div$  60) of 50  $\sim$  per sec., close  $S$  and by field regulation obtain some eight different currents on  $A$  (and hence values of  $I$ ) rising by about equal increments from 0 to the maximum safe value, noting the values of  $F$ ,  $A$ ,  $W$ ,  $V$  and  $C$  at each,  $F$ ,  $R$  and  $C$  being constant throughout.



(b) *Impedance with Capacity at Constant Frequency, Self-induction and Resistance.*

(3) Repeat obs. 2 for some eight different values of capacity  $C$  between 0 and the maximum possible,  $F$ ,  $R$  and  $A$  (i. e.  $L$ ) being constant throughout.

(c) *Impedances with Ohmic Resistances at Constant Frequency, Capacity and Self-induction.*

(4) Repeat obs. 2 for some eight different values of resistance  $R$  between 0 and the maximum possible,  $F$ ,  $C$  and  $A$  (i. e.  $L$ ) being constant throughout.

(d) *Impedance with Frequency at Constant Self-induction, Capacity and Resistance.*

(5) Repeat obs. 2 for some eight different frequencies between the minimum and maximum values possible,  $C$ ,  $R$  and  $A$  (i. e.  $L$ ) being kept constant.

Tabulate all your results as follows—

Self-Induction used: Nature or type . . . . . Ohmic Res. : . . . . . ohms . . .  
Ohmic Res. ( $R$ ) used: Nature or type . . . . .  
Capacity ( $C$ ) used: Type . . . . .  $p = \sin \phi$ .

Frequency $F$ Amps. $A$ Capacity $C$	Voltage across						Ohmic Res. $R = \frac{V_R}{I}$ Total $Z = \frac{V}{I}$ Wattmeter Reading across $P_0$ Total True Watts given to $P_0 = W$ Apparent Watts $\Delta V \cos \phi = W_e$ Power Factor $\cos \phi = \frac{W}{W_e}$ Angle of Lag $\phi$ Total Resistance $Z = \left( R^2 - \frac{1}{C^2} \right)^{\frac{1}{2}} = \sqrt{\left( \frac{V_R}{I} \right)^2 - R^2}$ Self-ind. $L = \frac{1}{p} \left( R + \frac{1}{Cp} \right)$
	$PQ$	$PM$	$MN$	$NQ$	$PN$	$MQ$	
	$V_{CR}$	$V_C$	$V_R$	$V_L$	$V_{CR}$	$V_{RL}$	
							Impedance $Z = \sqrt{\left( R^2 - \frac{1}{C^2} \right)^2 + R^2}$

(6) Plot curves having values of impedance as ordinates with each of the variables  $A$  (or  $L$ ),  $C$ ,  $R$ ,  $F$  and  $F$  in obs. 2-5 as abscissae on the same curve-sheet.

**Inferences.**—State clearly all that can be deduced from the results of the test.

**Note.**—The numerical and phase relations between the voltages across  $C$ ,  $R$  and  $L$ , and the combinations of these can

be studied in the above table with advantage and are highly instructive. From them the student should draw to scale the diagram shown in Fig. 116 above, for, say, two extreme values of the overall voltage  $V_{CRG}$  and see how the angle of phase difference  $\theta$  compares with that calculated in the above table.

### (115) Numerical and Phase Relations between Main and Branch Currents in Circuits containing Ohmic Resistance in Parallel with either Self-induction or Capacity.

**Introduction.**—The determination of the above relations between the main and branch currents in a circuit comprising ohmic resistance and self-induction in parallel is effected in detail in test No. 131, which should be done for the present test.

The numerical relations are at once seen in the table of results, while the phase relations are best seen from the diagram (Fig. 112) constructed for any particular set of simultaneous currents. It will be obvious that the relations will differ according to whether the self-induction branch  $PQ$  possesses appreciable ohmic resistance or practically none. Fig. 111 presumes the former condition, but if the latter obtains, then the current  $A_1$  in the non-inductive branch, being *in phase* with the voltage, will be given by  $OC$ , while that in the inductive branch  $A_2$  (having no resistance) lags just  $90^\circ$  *behind the voltage*, and will now be given by  $Ca$  (perpendicular to  $OC$ ), instead of by  $ba$  as in Fig. 112.

The present test should also be operated with capacity  $C$  substituted for the self-induction shown, when the student should have no difficulty in modifying both the tabular form of entry and the vector diagram to suit the new condition of capacity in parallel with ohmic resistance. If no resistance is purposely added to the condenser branch, the current in this will lead just  $90^\circ$  *in advance of the voltage*. Thus, the main or resultant current will be given by the diagonal of a parallelogram, the

sides of which will be at right angles and represent the branch currents.

### (116) Variation of Impedance and Phase Relations between the Currents in a Circuit containing Capacity and Self-Induction in Parallel.

**Introduction.**—The combination of self-induction in parallel with capacity is an extremely important one, and has some interesting and highly useful applications in electrical engineering which will be mentioned later. Referring to Figs. 118

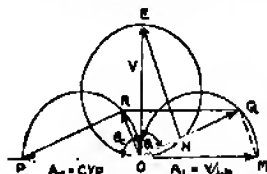


FIG. 118.

and 119. Let  $OE$  = the supply voltage  $V$ , and if the ammeter  $A_C$  and switch  $S_C$  add a negligibly small resistance to the condenser branch, the current  $A_C$  in this branch will  $= CVp$  and  $\tan \theta_c = \frac{1}{Cp\omega} = \infty$ , whence  $A_C$  will make an angle of phase difference  $POE = \theta_c = 90^\circ$  in advance of  $V$ .

Similarly, if the ohmic resistance of the self-inductive branch is negligibly small, the max. current  $A_L$  in this branch will  $= \frac{V}{Lp}$  and  $\tan \theta_L = \frac{Lp}{r} = \infty$ , whence  $A_L$  will lag behind  $V$  by an angle  $MOE = \theta_L = 90^\circ$ .  $OP$  and  $OQ$  are therefore the max. values of the respective branch currents. If, however, the self-ind.  $L$ , its current will be given by  $A_L = \frac{V}{\sqrt{L^2 p^2 + r^2}} = OQ$  lagging behind  $V$  by an angle  $\theta_L = QOE$ , such that  $\tan \theta_L = \frac{Lp}{r}$

(less than before). The total current  $A$  being the resultant  $OR$  of  $OP$  and  $OQ$  and making an angle  $ROE = \theta$  (seen to be one of advance in this case) with the voltage  $V$ .

The semi-circles  $ORP$  and  $OQM$  are the loci of the vectors representing the branch currents  $A_o$  and  $A_z$ , and it will be seen that the smaller the resistance ( $r$ ), the nearer will  $Q$  approach  $M$ , and the smaller will be the resultant or main current  $OR (= A)$  from the supply and the more nearly will it be in phase with  $OE (= V)$ .

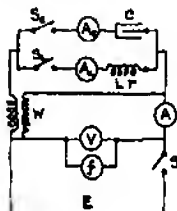


FIG. 119.

Thus at the *practical* limit,  $r$  will be very small,  $Q$  very close to  $M$ ,  $A_z$  nearly  $= A_o$  and nearly  $180^\circ$  out of phase with it, and  $OR$  very small and nearly *in phase* with  $V$ . Under these conditions *current resonance* is said to prevail in distinction to *pressure resonance* explained on p. 330 for series circuits. With current resonance in such a parallel circuit, the local current circulating in the loop may be many times greater than the main supply current  $A$ —a condition obtained when the idle or wattless components of the branch currents are practically equal, but of opposite sign when the wattless or idle component of the main current  $A$  will be less than that of either branch. Equal and opposite wattless currents in the branches will be obtained when

$$\frac{1/Cp}{1/C^2p^2 + r_o^2} = \frac{Lp}{L^2p^2 + r^2}$$

but as explained for series circuits this condition can only truly be called resonance when both  $r_o$  and  $r$  are negligibly small.

In practice we use capacity used for starting up alternating current motors; for nullifying the effects of the idle currents in a distributing system, thereby raising the power factor, and so increasing both the efficiency and economy of operation. The

capacity effect in this case is produced by an over-excited synchronous motor connected to the same supply.

**Apparatus.**—Source  $E$  of A.C. supply preferably a motor-driven alternator variable in speed and excitation within wide limits; frequency meter ( $f$ ); voltmeter  $V$ ; wattmeter  $W$ ; ammeters  $A$ ,  $A_0$  and  $A_L$ ; switches  $S$ ,  $S_0$  and  $S_L$ ; variable capacity  $C$ ; variable self-induction  $L$  of ohmic resistance ( $r$ ).

**Observations.**—(a) *Impedance with Self-induction at Constant  $f$ ,  $C$  and  $r$ .*

(1) Connect up as in Fig. 113, levelling and adjusting to zero such instruments as need it. Start the alternator with field regulator "full in," and see that the lubricating arrangements are working properly.

(2) With  $f$ ,  $C$  and  $r$  (if alterable) adjusted to convenient values, close  $S$ , and then  $S_0$  only, taking the readings of all the instruments.

(3) With  $f$ ,  $C$  and  $r$  as in obs. 2, close  $S_L$  and then  $S_L$  only and take the readings again.

(4) With  $f$ ,  $C$  and  $r$  again the same, close all 3 switches and by field regulations obtain some 8 different currents on  $A_L$  (and hence values of  $L$ ) rising by about equal increments up to a safe max. value, noting the readings of all instruments.

(b) *Impedance with Capacity at Constant  $f$ ,  $A_L$  (i.e.  $L$ ) and  $r$ .*

(5) Repeat obs. 4 for some 8 different values of capacity  $C$  at constant  $f$ ,  $r$  and  $A_L$  (i.e.  $L$ ).

(c) *Impedance with Ohmic Resistance ( $r$ ) at Constant  $f$ ,  $A_L$  (i.e.  $L$ ) and  $C$ .*

(6) Repeat obs. 4 for several values of ( $r$ ) if this is variable at constant  $f$ ,  $L$  and  $C$ .

(d) *Impedance with Frequency ( $f$ ) at Constant  $A_L$  (i.e.  $L$ ),  $C$  and  $r$ .*

(7) Repeat obs. 4 for some 8 different values of frequency ( $f$ ) at constant  $A_L$  (i.e.  $L$ ),  $C$  and  $r$ .

(8) By varying  $C$ ,  $L$ ,  $f$ , find the minimum value of  $A$  obtainable, noting the readings of all instruments at this, and tabulate all your results as follows—

Frequency $f$ .	
Voltage $V$ .	
Wattmeter Reading.	
True Watts $W$ .	
Amps $A$ .	
Appr. $A_C$ .	
Appr. $A_L$ .	
Apparent Watts $AV$ .	
Power Factor $\cos \phi = W/AV$ .	
Angle of Phase Diff. $\phi$ .	
$\cos \phi_L = \frac{1}{\sqrt{1 + \frac{L^2}{R^2}}}$	
$\phi_L$ .	
Capacity $C = A_C/pf$ .	
Self Ind. $L = \frac{1}{p} \sqrt{\left(\frac{V}{A_L}\right)^2 - r^2}$ .	
Impedance $V/A_C$ .	
Impedance $V/A_L$ .	

**Inferences.**—State clearly all the inferences which can be deduced from the above results.

### (117) Determination of the Load and Wattless Currents in an Inductive Alternating Current Circuit.

**Introduction.**—While the present investigation is bound up with that of power factor, considered in test No. 109, p. 316, the whole subject has such a vastly important bearing on the economical and efficient generation, transformation, and distribution of electrical energy, that a further consideration of it will be an advantage.

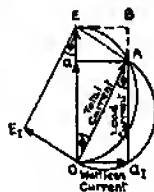


FIG. 120.

It is well known that of the power in watts, given by the product (amperes  $\times$  volts) "apparently" supplied to an inductive A.C. circuit or one containing self-inductance, or capacity, or both, only a portion constitutes an actual or useful load or power and does useful work in the circuit, while the other portion represents no load at all, and is said to be wattless or idle power, doing no work in the circuit.

The *useful power* is given by the product of that portion of the current and voltage in phase with each other, and is usually called the *true power*, while the wattless or idle power is given by the product of those portions of the current and voltage which are in quadrature, as it is termed, i. e. differ in phase by  $90^\circ$  or a quarter period, the average value of the latter product being always zero. The useful and wattless powers are each given by a product of *amperes*  $\times$  *volts*, and may be arrived at in either of two ways as follows: let a voltage  $OE$  and a current  $OA$  differ in phase by an angle  $\phi$ . Resolve  $OA$  into two components, one  $Ob$  along and in phase with  $OE$ , the other  $Ob_1$  perpendicular to it. Then  $OaOb_1$  is a rectangle, and the corner

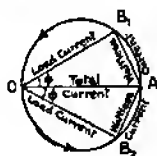


FIG. 121.

$a_1$  will lie on a semi-circle  $Oa_1A$  drawn on  $OA$  as diameter. We now have the true power  $= OE \times Ob$ , the wattless power  $= OE \times Ob_1$ , and the apparent power  $= OE \times OA$ .  $Oa_1A$  is, therefore, the triangle of currents of which  $OA$  is the total or resultant or ammeter current,  $a_1A$  the load or useful current, and  $Oa_1$  the idle or wattless current, always perpendicular to  $a_1A$ .

The power factor  $\cos \phi = \frac{OE \times Ob}{OE \times OA} = \frac{a_1A}{OA} = \cos Oa_1A$ .

Again, resolve  $OE$  into two components—one  $OA$  along and in phase with the current vector  $OA$ , the other  $OE_1$  perpendicular to it. Then  $OE_1EA$  is a rectangle and the corner  $A$  will lie in a semi-circle  $OAE$  drawn on  $OE$  as diameter. We now have the true power  $= OA \times OA$ , the wattless power  $= OA \times OE_1$ .  $OAE$  is therefore the triangle of voltages of which  $OE$  is the total or resultant or voltmeter voltage,  $OA$  in phase with the current, the load or useful or energy voltage, and  $OE_1$  the idle or wattless voltage always perpendicular to  $OA$ . The power factor  $\cos \phi =$

$$\frac{OA \times OA}{OA \times OE} = \cos AOE.$$

Now, the wattless powers in the two cases are  $OE \times Oa_i$  and  $OA \times OE_i$  respectively, which are equal, since the areas of the rectangles ( $OE \times Oa_i$ ) and ( $OA \times OE_i$ ) are equal. Mathematically, therefore, it is immaterial from which point of view the matter is treated, as both lead to the same result, namely—

True power = total voltage  $\times$  useful current =  $V \times I \cos \phi$ .

„ „ = total current  $\times$  „ voltage =  $I \times V \cos \phi$ .

In practice, however, it is more convenient and general to consider the total current  $I$  to be made up of two components, respectively  $I \cos \phi$  in phase with, and  $I \sin \phi$  in quadrature with, the voltage, and termed the energy, useful, or load current and the idle or wattless current. These are related geometrically, as seen in Fig. 121, by the equation

$$(\text{Total current})^2 = (\text{useful current})^2 + (\text{wattless current})^2.$$

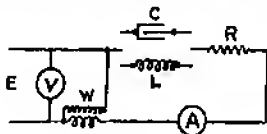


FIG. 122.

from which the wattless current measurement of the present test is deduced. This can be made with the two possible circuit conditions, namely, self-induction with ohmic resistance, for which the total current *lags* in phase behind the load current by an angle  $\phi$ , and capacity with ohmic resistance, for which the load current *lags* in phase behind the total current by an angle  $\phi$ , i.e. the total current *leads* in front of the load current. This is shown in the single diagram, Fig. 121, though more commonly by two separate ones split along the line  $OA$ .

**Apparatus.**—Source  $E$  of alternating current; voltmeter  $V$ ; ammeter  $A$ ; wattmeter  $W$ ; variable non-ind. resistance  $R$ ; capacity  $C$ ; self-induction  $L$ .

**Observations.**—(1) Connect up as in Fig. 122, levelling and adjusting to zero such instruments as need it.

(2) With  $C$  only connected in circuit, note the readings of  $V$ ,  $W$ , and  $A$  for some five or six values of current  $A$  between 0 and the maximum possible by varying  $R$ .



(3) With  $L$  only connected in circuit, repeat obs. 2 and tabulate as follows—

Nature of Circuit.	Voltage $V$ .	Watts $W$ .	Currents.			Power Factor $\cos \phi = W/VP$ .	Angle of Phase Diff. $\phi^\circ$ .
			Total (OA) = $A$ .	Load = $W/P$ .	Wattless = $\sqrt{A^2 - (W/P)^2}$ .		

(4) Check one or more of the tabular readings by diagram, such as Fig. 121.

**Inferences.**—State all that can be deduced from the results of the test.

### (118) Variation of Impedance, Reactance and Self-Induction with Position of Movable Core in Solenoidal Choker.

**Introduction.**—This test is intended to show the principle underlying the action of the so-called dimmer, which is so commonly used now in theatres and picture-halls for raising and

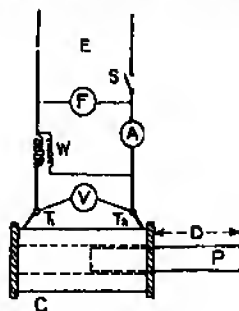


FIG. 123.

lowering the lighting when the supply thereto is alternating current, also the range of regulation of a choking coil for working on arc lamp circuits of different voltages. It has the great advantage over a variable "line" resistance of preserving completely the electrical continuity of the circuit, while introducing

a back E.M.F. of self-induction to the supply depending on the position of the movable core.

**Apparatus.**—Source of A.C. supply  $E$ , preferably an experimental motor-driven alternator, the excitation and speed of which are independently variable within wide limits; switch  $S$ ; frequency meter  $F$ ; ammeter  $A$ ; voltmeter  $V$ ; wattmeter  $W$ ; and the movable core solenoidal choker  $C$ .

**Observations.**—(1) Connect up as shown in Fig. 123, levelling and adjusting such instruments to zero as need it. Ensure that the lubricating arrangements are working properly on starting up.

(2) With the field regulator of  $E$  full in and the machine supplying constant frequency  $F$ , close  $S$  and adjust the alternator field excitation so as to give the max. safe current  $A$  through  $C$  with the centres of  $P$  and  $C$  coinciding (i.e.  $D = 0$ ), then note the readings of  $F$ ,  $A$ ,  $W$  and  $V$ .

(3) Take the readings of  $F$ ,  $A$ ,  $W$ ,  $V$  and  $D$  with the same constant values of  $F$  and  $A$  for each of a series of clamped positions of  $P$  between  $D = 0$  and  $D =$  full length of  $P$ , with  $P$  finally removed to a distance.

(4) Repeat obs. 2 and 3 for the same constant frequency  $F$ , but with  $V$  now maintained constant, at such a value as will prevent the current rising above the max. safe value when  $P$  is removed to a distance, and tabulate all your results as follows—

Choker coil. Length = . . . No. of turns = . . . Res.  $R =$  . . .  
Core Length = . . . Gross Section = . . .

Frequency $F$ .	Amps. $A$ .	Volts $V$ .	Distance $D$ .	Wattmeter Reading.	True Watts $W$ .	Apparent Watts $V A$ .	Power Factor $\cos \theta = \frac{W}{VA}$ .	Angle of Lag $\theta^\circ$ .	Impedance $V/A = \sqrt{L^2 + R^2}$ .	Reactance $X_p = \sqrt{(V/A)^2 - R^2}$ .	Coef. of Self-Ind. $L = \frac{1}{2\pi F} \sqrt{\left(\frac{V}{A}\right)^2 - R^2}$ .

(5) Plot curves for obs. 2 and 3 having values of  $D$  as abscissae with values of  $V$ ,  $W$ ,  $\cos \theta$ ,  $V/A$ ,  $Lp$  and  $L$  as ordinates respectively, and for obs. 4 having values of  $D$  as abscissae with values of  $A$ ,  $W$ ,  $\cos \theta$ ,  $V/A$ ,  $Lp$  and  $L$  as ordinates respectively.

**Inferences.**—State all you can deduce from the table of results and curves.

### (119) Effect of Length of Air Gap in a Closed Magnetic Circuit on Impedance, Reactance, Self-Induction, Current and Power.

**Introduction.**—The present test is a very important one, inasmuch that it is a direct proof of fundamental theory, and has an important bearing on the use and range of regulation of all kinds of choking or reactance coils for adjusting the current in arc lamp circuits at different voltages, while at the same time emphasizing the relative merits of "closed" and "open" magnetic circuits. The factors of an alternating current supply being voltage, current, and frequency, with the last named usually

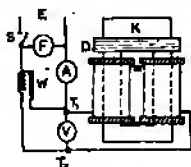


FIG. 124.

constant, it follows that the present investigation can be carried out in at least two ways, namely—

(a) With *constant* current and varying voltage at *constant* frequency.

(b) With *constant* voltage and varying current at *constant* frequency.

In the former method of supply, and with a series wound and connected choker, any effects observed by varying air-gap must be due to this alone. In the latter method, owing to change of current strength (in all but saturated magnetic circuits) causing a change of magnetic flux and induction density, any effects otherwise due to change in length of air-gap may be seriously vitiated.

**Apparatus.**—Experimental magnetic circuit with adjustable

air-gap; switch  $S$ ; frequency meter  $F$ ; ammeter  $A$ ; voltmeter  $V$ ; wattmeter  $W$ ; source of A.C. supply  $E$ , preferably from an experimental motor-driven alternator, the voltage and speed (i. e. frequency) of which are independently variable within wide limits.

**Observations.**—(1) Connect up as in Fig. 124, levelling and adjusting to zero such instruments as need it. Now start the motor-alternator, observing that the lubricating arrangements are working properly.

**Note.**—If a constant voltage and frequency town supply is used, a suitable non-inductive resistance must be connected in series with one of the mains on the *supply side of  $W$*  for regulating the current.

(2) Remove all the non-magnetic distancing strips  $D$  and clamp the laminated iron keeper  $K$  down on to the poles by means of the wing-nut clamp (not shown in Fig. 124). With the field-regulating resistance of the alternator full in, close  $S$  and obtain a frequency of 50 or 60 ~ per sec. on  $F$ , to be kept *constant* by driving the alternator at the requisite *constant speed*, where the frequency ( $f$ ) = No. of pairs of poles  $\times$  revs. per min.  $\div$  60.

(3) Raise the A.C. voltage by field regulation to the maximum value possible, so long as the current produced does not exceed the safe maximum for the choker winding. Then note the readings of  $F$ ,  $A$ ,  $W$ ,  $V$ , and that the air-gap is zero.

(4) Unclamp  $K$ , and carefully raise it *just sufficiently only* to slide one distance strip  $D$  in between it and the poles, and re-clamp  $K$ .

Now, lower the voltage (by field regulation) until  $A$  has the same value as before—the frequency being also the same. Then read  $F$ ,  $A$ ,  $W$  and  $V$ .

(5) Repeat (4) for about ten different air-gaps, increasing by one distance strip at a time, and finally with  $K$  removed altogether, i. e. air-gap = max.

(6) Employing supply condition (b), mentioned in the introduction above, with  $K$  removed altogether, adjust the field regulator of the alternator so as to give such a voltage as will send the max. safe current through the choker winding at the same frequency as before. Now note the values of  $F$ ,  $A$ ,  $W$  and

$V$ , and that the air-gap = max. This voltage and frequency is to be kept constant in futuro.

(7) Next take the readings of  $F$ ,  $A$ ,  $W$  and  $V$  for each of a series of air-gaps, ranging from that given by all the distance strips clamped together between  $K$  and the poles to none in at all, by one at a time, and tabulate all your results as follows—

Form of Inductive Circuit tested . . .

Section of: Core = . . . Yoke = . . . Keeper = . . .  
Distance Strips each = . . . Thick: Resistance of Choker winding R = . . . ohm.

Frequency $F$ .	$\Delta m_{\text{res}} \Delta$ .	Volts $V$ .	No. of Burds in use.	Length of Air Gap $D$ .	Wattmeter Reading.	True Watts $P$ .	Adjusted Watts $\Delta W$ .	Power Factor $\cos \phi = \frac{W}{\Delta P}$ .	Angle of Lag $\phi^\circ$ .	Impedance $Z/A = \sqrt{R^2 + X^2}$ .	Reactance $X = \sqrt{Z^2 - R^2}$ .	Cap. $C = 1/P(4\pi^2 - X^2)$ .	Coef. of Self Ind. $L = \frac{1}{4\pi^2} \sqrt{Z^2 - R^2}$ .
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(8) Plot curves from obs. 3-5 having values of  $D$  as abscissae with  $V$ ,  $W$ ,  $\cos \theta$ ,  $V/A$  and  $L$  as ordinates respectively. Also from obs. 6 and 7 plot curves having  $D$  as abscissae with  $A$ ,  $W$ ,  $\cos \theta$ ,  $V/A$  and  $L$  as ordinates respectively.

**Inferences.**—From a careful study of the above table and curves state clearly all that can be deduced.

(120) Investigation of Mutual Inductive Effects due to the Relative Positions of Two Coiled Circuits.

**Introduction.**—The object of this investigation is to find out to what extent, and in what way, two neighbouring electromagnetic fields may react on one another when in different relative positions.

Qualitative and quantitative results are obtainable which are both interesting and instructive, in view of how little the average student realizes the possibilities of interaction between neighbouring magnetic fields and apparatus with the prejudicial effects often resulting. For the investigation, two solenoidal movable iron core choking coils (preferably similar in all respects) may be used, connected in series.

**Apparatus.**—Two similar chokers; ammeter  $A$ ; voltmeter  $V$ ; wattmeter  $W$ ; frequency meter  $F$ ; switch  $S$ ; non-inductive resistance  $R$  (such as a bank of lamps) for regulating the current, if the supply  $E$  is from the town. If from an experimental motor-driven alternator,  $R$  can be omitted and  $A$  adjusted by field regulation on the alternator.

**Observations.**—(1) Connect up as in Fig. 125, where  $T_1T_2$  are the terminal extremities of the two coils connected permanently in series. Level and adjust to zero such instruments as need it.

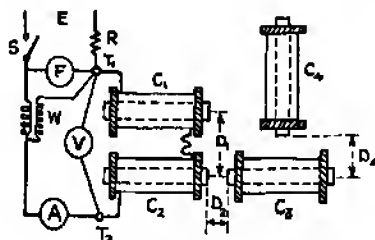


FIG. 125.

(2) With coils touching side by side in arrangement  $C_1C_2$  (i.e.  $D_1 = \text{minimum}$ ) and cores clamped centrally, take the readings of  $F$ ,  $W$ ,  $V$ ,  $A$  and  $D_1$  for constant full-load current  $A$  and frequency  $F = 50$  for each of a series of values of distance  $D_2$  up to a convenient maximum, the coils being parallel at each.

(3) Take a copy of an iron filing diagram for the position  $D_1 = \text{a min.}$

(4) Repeat obs. 2 and 3 with one coil reversed or turned through  $180^\circ$ .

(5) Repeat obs. 2 to 4 for the position of coils shown at  $C_3C_4$  (i.e. with magnetic axes of cores perpendicular) at different distances  $D_1$ .

(6) Repeat obs. 2 to 4 for the position of coils shown at  $C_5C_6$  (i.e. axes in line) at different distances  $D_1$ , and tabulate as follows—

Coil  $C_1$  used: Length = . . . No. of turns = . . . Res.  $Z =$  .  
                   Core length = . . . Cross section = . . .  
 Coil  $C_2$  used: Length = . . . No. of turns = . . . Res.  $R =$  . . .  
                   Core length = . . . Cross section = . . .

Relative Positions of Coils:	Distances $D_1, D_2$ and $D_p$	Frequency $F$ (Constant)	Current $A$ (Constant)	Volts $V$	True Watts $W$	Apparent Watts $A \times V$	Impedance $V/A$	Power Factor $\cos \phi = W/A \times V$

(7) In addition to the copies of the respective iron filing diagrams, plot the following curves having values of distance  $D$  as abscissae, with volts  $V$  and impedance  $\frac{V}{A}$  respectively, as ordinates in each case.

**Inferences.**—From the table of results, diagrams and curves state all that can be deduced.

### (121) Measurement of Magnetic Permeability by the Permeameter.

**Preliminary.**—The following method, devised by Prof. S. P. Thompson, is a simple and convenient workshop one for rapidly measuring the magnetic permeability ( $\mu$ ) of any material. It is quite distinct from the ballistic, direct magnetometric, or optical methods of measuring ( $\mu$ ), and is based upon the law of magnetic traction, viz. that the tractive force over a given area of contact is proportional to the square of the magnetic flux through the junction. This and all other traction methods are not capable of giving very accurate measurements of ( $\mu$ ), for both the tensile stress and the place chosen for contact between specimen and block may affect the results somewhat, as in the latter case the distribution of the induction is not very uniform at this point. Now, since in the permeameter the magnetizing coils remain fixed, the pull on the specimen core will be due to  $(B-H)$  lines, where  $B$  = induction per sq. cm. through the junction, and  $H$  = magnetizing force producing it. If  $S$  = sectional area of the junction in sq. cms. the force of attraction between core and block, i. e. Pull ( $P$ ) =  $(B-H)^2 S + 8\pi$  dynes =  $(B-H)^2 S \div (8\pi \times 453.6 \times 981)$  lbs.  $\therefore B = 1317 \times \sqrt{\frac{P}{S(\text{sq. in.})}} + H$  C.G.S. lines. Where  $P$  = pull in lbs. to detach.

If the magnetizing coil consists of  $T$  turns, carrying a current  $A$  amps., and its length between ends  $= l$ . Then  $H = \frac{4\pi AT}{10l} = KA$ , in C.G.S. measure. (The constant  $K = 4\pi T + 10l$ .)

An advantage with this method of measuring permeability is that the specimen of the material to be tested is in the form of a simple straight rod of circular cross section, and in this form it can generally be very easily obtained. Further, owing to no delicate ballistic galvanometer being used in the method, the test can be performed even in fairly close proximity to dynamos or near other magnetic fields without especially vitiating the results. The permeameter illustrated is fitted with a slip coil  $CC$  for measuring  $\mu$  ballistically if desired. For a more detailed description of the instrument *vide* p. 615.

**Apparatus.**—Permeameter (Fig. 280); Salter's spring balance; ammeter  $A$ ; rheostat  $r_2$  (p. 599); battery  $b$ ; switch  $K_1$ ; Pohl's commutator or reversing switch  $S$  (p. 584); specimen or rod  $R$  to be tested.

**Tests.**—(1) Connect up as indicated in Fig. 126, omitting the ballistic circuit shown at the lower part of the Fig. Insert a specimen in the coil after having cleaned the end and demagnetized it. Then attach the spring balance by means of its double hook to the pin  $pp$  in the present case.

(2) With  $r_2$  full in, adjust the current to a small value (say 0.02 amp.), and note the force  $P$  lbs. required to detach. This should be repeated

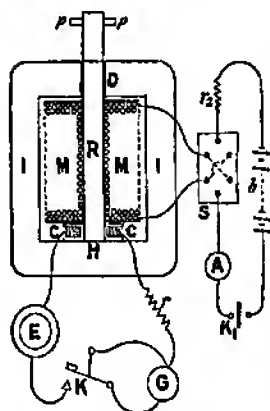


FIG. 126.

two or three times, and the mean noted.

(3) Repeat 2 for about fifteen different currents up to the maximum (about 7 amps.), rising by such amounts as will give about equal increments of pull on the balance.



(4) Repeat 2 and 3 for different specimens, and tabulate as follows—

NAME . . .

DATE . . .

Specimen tested.				Magnetizing.		Pull P lbs.	Induction $B$ .	Permeability $\frac{\mu}{R}$
No.	Nature.	Diameter $d$ (ins.)	Section ( $S$ ) $= \frac{\pi d^2}{4}$ sq. in.	Current $I$ amp.	Force $H = KI$ .			

(5) Plot two curves, one having  $H$  as abscissa and  $B$  as ordinates, the other having  $B$  as abscissa and  $\mu$  as ordinates.

### (122) Measurement of Magnetic Permeability (by Hopkinson Permeameter).

**Introduction.**—The present test is very similar to the preceding one (No. 121), except that a slightly different form of



FIG. 127.

permeameter, devised by Professor Hopkinson, is provided. This instrument consists (as seen in Fig. 127) of a heavy wrought-iron yoke with two magnetizing coils, one having a fixed core and the other a movable one. On the movable core is a small coil of wire which, when the core is withdrawn, is jerked up by a spring; this coil is connected to a ballistic galvanometer, and the throw is proportional to the lines in the core; by this means cores made of various samples may be compared for permeability. The apparatus and connections, except for the differ-

ence in the actual form of permeameter, and the addition of a ballistic galvanometer  $G$ , key  $K$ , adjustable standard known resistance ( $r$ ), and earth inductor  $E$ , or preferably a standard solenoid, are precisely those indicated in Fig. 126, and the student should read the introductory remarks of test No. 121.

The evaluation of the throws on the ballistic galvanometer  $G$  is exactly as given in the introduction to test No. 78, and therefore need not here be repeated.

**Observations.**—These consist in taking the galvanometer first throw at the moment when the small slip-coil springs out, for each of a series of exciting currents ranging from 0 to the safe maximum permissible, and tabulating all the readings and evaluated results in a convenient form.

**Note.**—The first throw should be repeated, *for each excitation*, by replacing the slip-coil two or three times, when the mean throw only at each current should be tabulated. Further, a preliminary trial must be made, before taking the above series of observations, by adjusting the resistance ( $r$ ) until maximum permissible exciting current gives a mean first throw, not exceeding full-scale deflection. Lastly, the increments of current in the series must be smaller during that part of the range where the magnitude of the mean throws appears to be differing considerably.

A curve should be plotted between values of induction density  $B$  found, as ordinates, with values of magnetizing force  $H$  as abscissae, and also one between permeability  $\mu$  as ordinates, and values of  $B$  as abscissae.

### (123) Measurement of Magnetic Hysteresis and Eddy or Foucault Currents in Samples of Magnetic Material. (By Single Phase Alternating Currents.)

**Introduction.**—The determination of magnetic hysteresis in magnetic materials by some of the most important methods is given in considerable detail in *Practical Electrical Testing* by the author, and the reader is referred to this book for further particulars of these tests. It is of course well known that an iron

core, magnetized by an alternating current of electricity, is the seat of two distinct losses of power, (1) from hysteresis, and (2) from eddy currents generated in the transverse section of the conductor.

The former depends on the induction density in the iron, the frequency of the alternating current, and on the volume and nature of the magnetic material in question. No amount of lamination will get over this loss.

The latter source of power loss is dependent on the extent of lamination of the iron and on the transverse section of each individual portion of the core.

Now by employing sufficient iron in a test specimen, *well laminated*, the eddy current loss can be made small compared with the hysteresis loss, whence any measurement now made of the total core or iron loss will for all practical purposes represent the hysteresis loss simply. This is the principle upon which the present method is based, but if greater accuracy be desired the results so obtained can easily be checked by one of the methods given in the above-mentioned work.

It will thus be at once evident from the foregoing remarks that the iron employed in all electrical engineering appliances, but more particularly in alternating current ones, should be tested for hysteresis loss prior to being used in the construction of such appliances. The present method is one of the simplest and most expeditious ways of measuring the hysteresis loss in different samples of iron which may be to hand, and it is accurate enough for most practical purposes.

Probably the most important direction in which the preceding remarks find an application is in transformer, alternator, and alternating current motor work. As the magnetic circuits of such appliances are built up of stampings-out of thin soft sheet iron, this latter is the form in which samples to be tested usually come to hand. Assuming therefore that a few large sheets of the material to be tested, the thickness of which usually varies from 0.35 m.m. to 0.5 m.m. for transformers and up to about 1 m.m. for alternators, etc., is at hand, the first thing to do is to prepare the material for testing by constructing a small transformer out of it thus—

## PREPARATION OF IRON SAMPLES FOR TEST.

Cut such a number of strips out of the sheet, each about  $12'' \times 2''$  as will make four equally thick piles, each containing the same number of strips, placed on the top of one another like the leaves of a book, to a thickness of, say,  $\frac{1}{2}''$  and each weighing about 2 lbs.

Now remove any burr from the edges of each by means of a file, and weigh all the strips, noting the total weight of iron  $W$  which should preferably be 8 or 10 lbs.

Next varnish *one side of each strip* with thin shellac varnish, and when dry assemble into four equal piles with varnished faces all pointing one way. Bind each pile, to within  $1\frac{1}{2}''$  of each end, with a layer of thin prepared tape, when each will be ready to receive the magnetizing coils. It will be noticed that each strip is insulated from the next by the equivalent of one layer of thin varnish, which is all that is needed. Next make a thin rectangular cardboard tube about  $4''$  to  $4\frac{1}{2}''$  long for each pile and capable of just slipping easily over it. Wind each of these with two distinct coils of, say, No. 18 double cotton-covered copper wire, each coil consisting of two layers and the two coils wound one over the other. Place the four bundles of strips with their coils in position so as to form a rectangular frame of iron with adjacent ends *interleaved*, so to speak, and clamped together so as to form a compact joint of low resistance. Join the four coils of each set together so that they would help one another in magnetizing the ring and the specimen is then ready for test. Note the total number of turns  $N_p$  and  $N_s$  on both primary and secondary coils respectively, also the cross section  $S$  sq. cms. of iron in the frame, i.e. thickness of strip  $\times$  by number side by side  $\times$  width of strip, and the mean length of the path of a line of force right round.

**Apparatus.**—Iron core on frame  $I$  to be tested and wound with the two distinct (closely-wound) primary and secondary coils  $P$  and  $S$ . Siemens electro-dynamometer or Farr direct reading dynamometer ammeter  $A$  (Fig. 577); non-inductive Wattmeter  $W$ ; non-inductive rheostat  $R$  (p. 597); switch  $K$ ; electrostatic voltmeter  $V$ ; Pohl's commutator  $D$  (p. 584), or other suitable change-

over switch for throwing  $V$  in quick succession across  $P$  or  $S$ . Source of alternating current supply  $E$ , preferably one the frequency of which is under control; a tachometer will be required in this latter case.

**Observations.**—(1) Connect up as indicated in Fig. 128, and adjust the pointers of  $A$ ,  $V$  and  $W$  to zero if they require it and levelling them where necessary. If the alternator is under control see that all the lubricating cups in use feed slowly and properly.

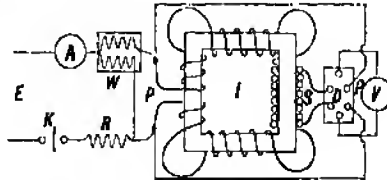


FIG. 128.

(2) Start the alternator up to its highest desirable speed, which is to be kept constant, then with  $R$  at its full close  $K$  and alter  $R$  and the excitation to give the smallest readable current on  $A$ . Note simultaneously the readings on  $A$ ,  $W$  and  $V$  in quick succession when across  $P$  and  $S$  by turning  $D$  to  $P$  or  $S$  as the case may be, and the speed.

(3) Repeat 2 at the same speed for eight or ten different currents  $A$ , rising by about = increments to the highest desirable.

(4) Adjust the current  $A$  to some convenient value, preferably one that will produce an induction of  $B$ —about 4000 lines per sq. cm. in  $I$  and keep this constant.

(5) Now take a series of readings of  $W$  and  $V$  for about eight or ten different speeds, ranging from the greatest down to the smallest, noting the value at each.

(6) Measure the resistances of the primary and secondary windings by means of a Wheatstone Bridge set, and tabulate all your results as follows—

NAME . . .

DATE . . .

Alternator: Periods per Revola.  $K = \dots$   $\gamma = 2\pi n = \frac{2\pi KN}{60}$  per sec.  
 Resistances (hot) Primary  $R_p = \dots$  ohms. Section of Iron Core  $S = \dots$  sq. cms.  
 " " Secondary  $R_s = \dots$  " Weight of " "  $W = \dots$  lbs.  
 No. of Turns: Primary  $N_p = \dots$  Secondary  $N_s = \dots$  Thickness of Strips = . . .  
 Wattmeter Constant = . . .

Speed of Alternator $N$ revs. per min.	Frequency $n = \frac{KN}{60}$ per sec.	Current		E.M.F.		Power.		Approx. loss in Primary $4R_p$	Mean Core Loss Total = $P - 4R_p$ = $P$ approx.	Hysteresis loss Per sq. in. Iron $H/W$	Mean Core Induction $B = \frac{N_s I_s}{S}$ per sq. cm.
		Deflection on $A$ .	True Ampe. ( $d$ ).	Primary $I_p$	Secondary $I_s$	Reading on $W$ .	True Watts ( $P$ ).				

(7) Plot the following curves--

- Between  $H$  and  $B$  having  $B$  as ordinates and hysteresis loss  $H$  as abscissae.
- Between  $H$  and  $n$  having  $n$  as ordinates and hysteresis loss  $H$  as abscissae.
- Between  $H$  and  $A$  having  $A$  as ordinates and hysteresis loss  $H$  as abscissae.

**Note.**— $B$  varies from 3000 to 5000 C.G.S. lines in ordinary transformers. With good iron  $H/W$  should not exceed  $\frac{1}{2}$ .

**Inferences.**—State very clearly what you can infer from the results of your tests.

### (124) Separation and Measurement of Iron Losses in the Cores of Alternators, Transformers, Motors and other Electro-magnetic Appliances. (Alternating Current Frequency Method.)

**Introduction.**—The iron losses taking place in the cores of alternating current plant (e.g. alternators, transformers, motors, etc.) consist of those due to magnetic hysteresis and eddy or Foucault currents respectively.

The **Hysteresis Loss** depends on the induction density in the iron core, the periodicity of the supply current, and on the volume and quality of the iron used, but in no way on the extent

to which the lamination of the core is carried and increases with, but more rapidly than, the induction.

Steinmetz gives the empirical equation for the work done on account of hysteresis as  $w = \eta \beta^{1.6}$  ergs per cycle of current and magnetization where  $\eta$  equal the hysteretic constant which may vary from 0.001 to 0.003 for soft, annealed core plates, and  $\beta$  = maximum value of induction density in lines per sq. cm.

If ( $n$ ) = periodicity of the supply or number of complete periods per second, the effective loss  $W_h$  due to hysteresis (per cub. cm. of core) will be

$$W_h = \eta n \beta^{1.6} \text{ ergs per sec.} = \eta n \beta^{1.6} 10^{-7} \text{ watts,}$$

on the assumption that the hysteresis loss per cycle is independent of the rate of cycle which the latest research shows to

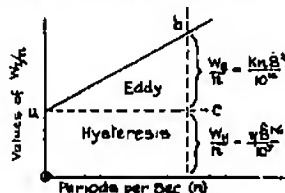


FIG. 129.

be not quite the case, though sufficiently so for practical purposes. Actually the hysteresis loss per cycle increases slightly with increase of periodicity, and from the above relation we see that for a given core, run at constant induction density  $W_h$  is  $\propto n$ .

The **Eddy Current Loss** depends on the strength of the induced eddy currents set up in the thickness of each lamina composing the core, and hence, by Ohm's law, will vary as the square of such strength. The eddy currents are due to the varying flux through the core, and will depend on the rate of variation of this flux, i.e., on the periodicity ( $n$ ). Thus the eddy current loss will vary in proportion to  $n^2$ , and the effective loss  $W_e$  due to eddy currents (per cub. cm. of core) will be

$$W_e = K n^2 \beta^2 10^{-16} \text{ watts,}$$

where  $K$  = a constant taking into account the specific electrical resistance of the iron and the thickness of plate lamina.

AA

Eddy currents tend to reduce the flux in a core due to their demagnetizing action and also cause a non-uniform distribution over the sections of the laminae. Due to this, the hysteresis loss will be further increased with increasing values of  $(n)$ , and will appear as an increase in the eddy current constant ( $K$ ) in the present method over and above the calculated value. Especially will this be the case if the insulation between core laminae is not all effective.

If  $W$  = the total power in watts absorbed by any electromagnetic appliances  
and  $W_e$  = the watts absorbed or expended in the exciting coil,  
then the nett iron losses

$$= W_i = W - W_e = W_a + W_s = \eta n^2 \hat{B}^2 10^{-7} + K n^2 \hat{B}^2 10^{-11} \text{ watts.}$$

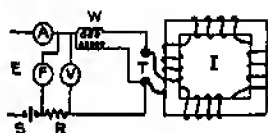


FIG. 130.

Now the coefficients  $\eta$  and  $K$  can be found experimentally by testing the appliance at constant induction density  $\hat{B}$  with alternating current at variable periodicity ( $n$ ). This can be done by varying the speed of an alternator running at constant excitation, for then the voltage  $V$  varies  $\propto$  to the periodicity ( $n$ ), so that  $V/n$ , and hence the flux, remains constant. On plotting the values  $\frac{W_i}{n}$  as a function of the induction  $\hat{B}$ , the straight line  $ab$  is obtained corresponding to one particular value of  $\hat{B}$  and of  $V/n$ . From the curve  $ab$  and this value of  $\hat{B}$  the coefficients  $\eta$  and  $K$  can be calculated, and hence the hysteresis and eddy current losses respectively.

**Apparatus.**—Electro-magnetic core  $I$  to be tested; low-reading alternating current ammeter  $A$ ; wattmeter  $W_1$  and voltmeter  $V$ , each independent of periodicity; frequency meter  $F$ , or, failing this, a tachometer for measuring the speed of the supply alternator  $E$ ; switch  $S$  and non-inductive variable resistance  $R$ .

**Observations.**—(1) Connect up as shown in Fig. 130, levelling and adjusting to zero such instruments as require it. Start up



the experimental alternator and see that the lubricating arrangements are working properly.

(2) With a suitable ammeter, variable regulator, and switch in series with the alternator field across the D.C. supply, close the field switch T/S, and adjust the speed to give the lowest readable value of periodicity ( $n$ ) on  $F$  (or smaller value by tachometer), and adjust the field regulator to give some suitable reading on  $V$ . Now note the readings of all the instruments, and particularly the value of  $V/n$  for future use.

(3) Note the readings of all instruments for each of a series of periodicities ( $n$ ) up to the highest permissible, taking care that the value of  $V/n$  (and therefore the value of the induction  $\beta$  in  $I$ ) is the same at each periodicity.

(4) Repeat the above for the same range of periodicity, but for each of two other widely different values of  $V$ , giving corresponding values of the ratio  $V/n$  (and hence inductions  $B$ ) kept constant throughout each range of  $\sim$  variation.

**Note.**—If the appliance tested will safely stand, say, 150 volts, then three values of the constant  $1\frac{1}{2}$  might be used, viz.—

$$\frac{150}{50}, \frac{100}{50} \text{ and } \frac{50}{50} \text{ or } 3, 2 \text{ and } 1 \text{ by suitable variation of}$$

field excitation, thus giving three corresponding values of  $\hat{B}$  in the core. Further, since  $\frac{W_f}{W_0}$  is not likely to exceed 1.5 or 2.0

watts per lb. in modern iron cores, a low-reading wattmeter will be required, unless the core is a heavy one.

Tabulate as follows—

Name \_\_\_\_\_ Date \_\_\_\_\_

Supply & Demand: Periods 1997-1998,  $P = \dots$ 

Core tank: Furnace type . . .

Markus, . . .

Mean length of magnetic circuit  $l =$

உள்ளுறை: உலகம்

Net cross section of iron 2 m

014109; tumpu y = 000 41722.

Nut weight of fruit	19.83
---------------------	-------

core innovations =

Net volume of mag	7.00
-------------------	------

• **Insulin resistance** =

Alternating Speed in r.p.m. $N_s$	Frequency $n = \frac{N_s}{60}$ per sec.	Voltage $V$	Calculated Constant $1/a$	Amps. $A$	Max. Ind. Drive $\frac{A}{2}$	Total Watta. $W$	Copper Loss $P_{cu}$	Total Iron loss $W_{Fe}$ as in $4b$	Iron loss per lb. of iron $W_{Fe}/W_{Fe}$
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(5) Plot curves having values of ( $n$ ), as abscissae, with values of  $V$ ,  $A$  and  $W$ , respectively, as ordinates, for each constant  $V/n$  taken.

(6) Determine the hysteresis and eddy current coefficients, and from 7 draw a straight line, tangent to the curve relating  $W$ , and  $n$ , separating the hysteresis and eddy losses, when ordinates of this line will represent losses due to hysteresis  $\propto n$ , while the ordinate intercepts between it and the watt curve will represent losses due to eddy currents  $\propto n^2$ .

**Inferences.**—State clearly what you can infer from the above results.

### (125) Measurement of Magnetic Hysteresis by Ewing's Hysteresis Tester.

This instrument, a general view of which is seen in Fig. 131, and for a full description of which see Professor Ewing's Paper in the *Journal of the Institution of Electrical Engineers*, April 25, 1895, has been designed to meet the want which has been felt of a means of testing the magnetic hysteresis of sheet-iron or steel in a simple and expeditious way suitable for workshop as well as laboratory use. A few strips of the sheet metal to be tested are cut or stamped, five-eighths of an inch wide and three inches long. They are filed to the exact length when clamped in a gauge, which is provided with the instrument, and are then inserted in a carrier which is made to revolve by turning a handle. The carrier turns between the poles of a permanent magnet, which is suspended on a knife-edge. In consequence of the hysteresis of the specimen the magnet is deflected, and the amount of its deflection is observed by means of a pointer and scale. From this deflection the hysteresis of the specimen is determined. The magnetic induction is practically the same in all specimens, notwithstanding differences in the permeability of the iron, on account of the comparatively large air-gap between the specimen and the magnet poles.

Two standard samples are provided with the instrument,

having stated amounts of hysteresis. The test of any other specimen is made simply by comparing the deflection produced by it with the deflections produced by the standard samples. This serves to determine the hysteresis of any specimen in absolute measure.

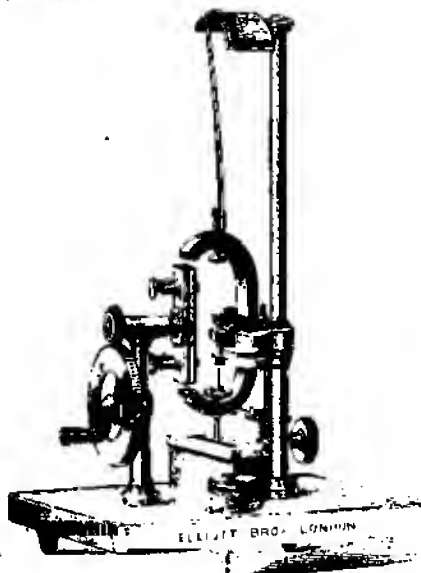


FIG. 131.

The operation of the instrument is entirely mechanical, and requires no knowledge of electrical testing.

**(126) Measurement of the Impedance, Reactance, and Self-Induction of Alternator Armatures, Motor Stators, Transformer and other windings (by Alternating Currents).**

**Introduction.**—The following is a simple and an approximate method of finding the self-induction  $L$  of an inductive circuit. It depends on the fundamental relation subsisting between current ( $A$ ) and impressed E.M.F. ( $V$ ) in such a circuit, namely—

$$A = \frac{V}{\sqrt{L^2 p^2 + R^2}}$$

or, as it may otherwise be written,

$$\text{Impedance} = \sqrt{L^2 p^2 + R^2} = V/A,$$

where the angular velocity of the current  $p = 2\pi n$ ,  $n$  being its frequency in  $\sim$  per sec.

Since by definition, the coefficient of self-induction  $L$  of any coiled circuit is  $= \frac{N}{A}$  where  $N$  is the total magnetic flux threading the coil and produced by a current  $A$ , it follows that if the inductive circuit encloses, and is surrounded by, a non-magnetic medium, the value of  $L$  calculated will be the same for all values of  $A$ . If, however, it encloses an iron core, any variation of  $A$  will produce variations in the permeability of, and consequently the flux in, the core, and the value of  $L$  will vary with  $A$ .

Thus the impedance and self-induction of the primary of a static transformer, and of the stator winding of an induction motor will decrease as the secondary load of the former and B.H.P. developed by the latter increases, owing in each case to alteration of current and core flux. The same effect occurs with the armature of an alternator or of a synchronous motor, the impedance and self-induction of which will vary with—

(1) The armature current, since the core flux and permeability will vary inversely together as the current changes.

(2) The magnetization of the core due to any variation of the field-magnet strength.

(3) The type of winding used, i.e. whether "distributed" or

"concentrated," the former having small self induction owing to the circuits being partly in both favourable and unfavourable positions for linking with the flux, the latter having a large self-induction, due to all the circuits in certain positions in the revolution linking up simultaneously with the flux.

(4) The reciprocal of the length of air-gap between armature core and field poles.

(5) The exact position of the armature relatively to the field poles, especially with windings concentrated into single slots.

(6) The induced currents in the pole pieces and field windings due to the armature current.

In view of the above considerations, it will therefore be obvious that the value of the impedance or self-induction of the armature of an alternator available for calculation can only be a mean value as obtained in the manner indicated in the present list.

Two methods of procedure are possible, according as to the mode of obtaining the Ohmic resistance  $R$ .

(a)  $R$  may be measured in the usual way on a Wheatstone Bridge either before or after the test, in which case a measurement of the current at a known voltage, or *vice versa* together with (n), at once gives the self-induction  $L$ .

(b)  $R$  may be obtained by Ohm's Law in terms of a continuous current and pressure when this latter is available, and therefore no Wheatstone Bridge is necessary. This method of procedure, which is the one adopted in the present instance, has the further advantage that in cases where  $R$  is liable to heat up, due to the current, its value will be obtained correctly, which would not be so if obtained by the bridge.

The following precautions should, however, be carefully observed, and are practically the same as appear in the measurement of the resistance of an electric glow lamp while running (*vide* p. 47).

If the voltmeter is shunted across the terminals of  $I$ , then its reading is correct, but the *true current through  $L$*  which is required = *ammeter reading - voltmeter current*. If, therefore, an electrostatic voltmeter is employed this correction does not occur, but if a hot wire voltmeter is used, the correction should be made, as the voltmeter current is not usually negligibly small compared with the main current.

If the voltmeter is across the ammeter and  $L$  combined, then the true voltage across  $L = \text{voltmeter reading} - \text{voltage absorbed in ammeter}$ . Owing to the low resistance of the last-named usually, this correction is negligible, but must be made if the ammeter resistance is considerable. In this arrangement we also have—

*True self-induction of coil = calculated  $L$  - self-induction of ammeter.*

The test can be performed either using the same voltage from the direct and alternating sources and noting the relative currents, or employing the same current and observing the relative direct and alternating volts necessary to send this current through the circuit, the frequency in either case remaining the same.

In the present instance the latter way will be adopted as being more readily applied.

**Apparatus.**—Inductive circuit  $L$  to be tested; alternating current voltmeter  $V$ , preferably electrostatic; Siemens electro-

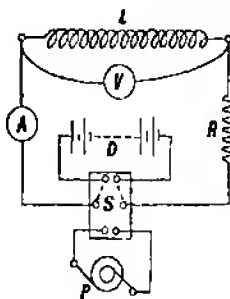


FIG. 132.

dynamometer or A.C. ammeter  $A$  (Fig. 251); variable non-inductive resistance  $R$  (p. 598); change-over switch  $S$  (p. 582); alternator  $P$ , with its tachometer; direct current dynamo or secondary battery  $D$ .

**Observations.**—(1) Connect up as indicated and adjust the pointers of  $A$  and  $V$  to zero. Before starting see that all lubricators in use feed slowly.

(2) Make  $R$  as large as possible and switch  $S$  over to  $D$ , adjusting  $A$  to the maximum current which

$L$  will carry. Note the current  $A$  amps. and the volts  $V_D$  across  $L$ .

(3) Turn  $S$  over to  $P$  and adjust  $R$  and the speed of  $P$  so as to again obtain the same current  $A$  amps. Note the volts ( $V_P$ ) and the speed of alternator.

(4) Open  $S$  and make  $R$  as large as possible again. Repeat 2 and 3 for about ten different decreasing values of current to the smallest convenient, and keep the speed of  $P$  constant throughout, its excitation being varied, if necessary.

**Note.**—If the double pole change-over switch  $S$  is not available, the common circuit containing  $A$ ,  $L$  and  $R$  can be closed to  $D$  through a single pole switch, and a series of pairs of values of  $A$  and  $V$  first taken in order to obtain the ohmic resistance  $\left(\frac{V}{A}\right)$  of  $L$ .  $P$  can then be substituted for  $D$ , and a similar series taken with alternating currents of the same scale values on  $A$  as before between 0 and the maximum  $I$  will carry at constant frequency.

(5) If the inductive circuit has a removable magnetic core, as, e.g., in the control movable core open-magnetic-circuit type of choking coil. Then operate obs. 2-4 above, or the alternating current series only of observations mentioned in the *Note* above, with the core (a) central in the coil, (b) removed altogether away from the coil.

(6) If the inductive circuit  $L$  (Fig. 132) consists of the armature of an alternator the impedance and self-induction of which is required, the A.C. supply should have the same periodicity as the normal value for the machine under test. Then, with the field magnets of the machine under test, *unexcited* vary  $R$  so as to obtain about a quarter, half, three-quarters and full-load currents ( $I$ ) through the armature, noting the corresponding readings of  $V$  at each of a series of positions of the armature throughout a fraction of a revolution equal to half the polar pitch.

(7) Repeat (6) with normal field excitation and tabulate as indicated.

(8) Plot curves for each fraction of full-load current having impedance and self-induction respectively as ordinates with positions of armature throughout the half polar pitch as abscissae.

**Inferences.**—State clearly all that can be deduced from the results of the test, and find the average value of the impedance and self-induction, and tabulate as follows:—





methods; the other qualities are much more difficult of determination, and almost numberless methods have been devised for obtaining them.

In general it may be remarked that relative or comparative measurements are more accurate than absolute ones, though the final results might be completely vitiated by comparing with an inaccurate standard. The former remark results in the difficulty experienced in accurately measuring an alternating current, and from the fact that its E.M.F. wave may differ considerably from that of a sine curve.

In employing condensers in methods of measuring self and mutual induction, considerable difficulty is usually met with in the phenomena of electric absorption. Professor H. H. Rowland has found that this can be represented by a resistance placed in series with the condenser, which resistance is a function of the square of the current period.

### (127) Absolute Measurement of Self-induction (by Alternating Currents).

**Introduction.**—The following method of measuring the self-induction of a coil, due to Professor Rowland, necessitates the employment of ordinary single phase alternating currents of electricity with an electro-dynamometer specially constructed, so as to be as sensitive as possible. It is possible to make such an instrument, having its fixed and moving coils connected up to two distinct pairs of terminals, that it will detect 0.0001 of an ampere with a self-induction in the suspended coil not exceeding 0.00075 henries, and in the fixed coil of not more than 0.0006 henries, capable of carrying about 0.1 ampere comfortably.

Such an instrument obviates the necessity for using large currents in order to obtain accuracy and sensibility. If  $(d)$  = the deflection of the swing coil from zero when its plane was perpendicular to that of the fixed coil,  $C_1$  and  $C_2$  = strengths of the alternating currents flowing through the movable and fixed coils and having an angle of phase difference  $\theta$ . Then  $d \propto C_1 C_2 \cos \theta$ .

The principle of the present method consists in adjusting  $C_1$  and  $C_2$  to a phase difference of  $90^\circ$ .

In deflection methods  $\cos \theta$  is greater than 0, while for zero methods  $\cos \theta = 0$ . In the former the self-induction is obtained in terms of resistance and the angular velocity of the current  $p = 2\pi \times$  frequency, which consequently require that ( $n$ ) the frequency should be constant and accurately known to at least 1%, in which case the results will probably agree to within about the same amount.

**Apparatus.**—The electro-dynamometer, of which ( $f$ ) is the fixed, and ( $m$ ) the moving coil; non-inductive resistance  $r$ ; source of alternating current; and the self-induction  $L$  to be measured; switch  $S$ ; rheostat  $Rh$  (non-inductive).

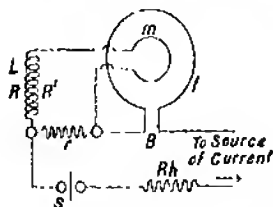


FIG. 133.

**Observations.** — (1) Connect up as indicated in Fig. 133, placing  $L$  and a non-inductive resistance  $R$  in series with the moving coil ( $m$ ), and the combination across the terminals of a re-

sistance ( $r$ ) in the main circuit in which the fixed coils are also placed.

(2) With the moving coil adjusted to zero,  $Rh$  at a maximum, close  $S$ , and obtain a convenient deflection  $d$  by adjusting  $Rh$  and the non-inductive resistance  $R$  in the moving coil circuit. Note this deflection ( $d$ ) and the speed ( $N$ ) or periodicity ( $n$ ) of the alternator and the added resistance  $R$  in circuit with  $L$ .

(3) Remove the self-induction ( $L$ ) which is being tested, and add a non-inductive resistance to the swing coil circuit such that the same deflection ( $d$ ) as before is reproduced. Note the new resistance  $R'$  in the circuit, the frequency ( $n$ ) per sec. being the same as before.

(4) Calculate the self-induction  $L$  tested from the relation

$$L = \sqrt{\frac{(R' - R)(R + r)}{p^2}} = \frac{1}{2\pi n} \sqrt{(R' - R)(R + r)} \operatorname{sech} \cos \theta,$$

and tabulate as follows—

Name . . . . . Date . . . . .  
 Alternator: Periods per revolution  $\frac{1}{p} = \dots$   $p = \text{revs.}$   
 Self-induction tested: Nature . . . . .

Speed of Alternator $N$ revs. per. min.	Frequency $\omega = \frac{2\pi N}{60}$ per. sec.	Resistances.			Deflection ( $d$ )	Self-induction	
		$r$ .	$R$ .	$R'$ .		$L$ .	Mean $L$ .

(5) Repeat 2—4 for different deflections ( $d$ ) at constant frequency. Also for different frequencies with the same deflection.

N.B.—Great care must be taken to keep the frequency constant throughout any pair of readings.

### (128) Comparison of Two Coefficients of Self-induction (by Alternating Currents).

**Introduction.**—When an accurate standard known self-induction is available the value of an unknown induction can be more accurately determined by comparison, for in this case the measurement is independent of frequency. The following method due to Professor Rowland is a zero one, and is similar in many respects to the preceding method, though this was a deflection method. The effects of induction and electrostatic action of the various parts of the circuit on one another must be carefully avoided as much as possible, and in this connection it should be remembered that a twisted twin lead possesses the latter quality.

**Apparatus.**—The unknown self-inductions  $L_1$  to be compared, with a standard  $L$  (known); non-inductive resistances  $r$ ,  $R$ ,  $R'$  and rheostat  $Rh$ ; switch  $S$ ; source of alternating current  $E$ ; electro-dynamometer of which ( $f$ ) is the fixed and ( $m$ ) the moving coil.

**Observations.**—(1) Connect up as in Fig. 124, the coils  $L_1$ ,  $L_2$  being together, and adjust the moving coil to zero.

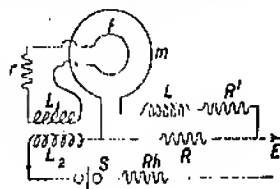


FIG. 124.

(2) With  $Rh$  large close  $S$ , and adjust the current to a

convenient value, and adjust  $R$ ,  $R'$  and  $r$  so as to get no deflection of the moving coil for the currents in  $f$  and  $m$ .

(3) Calculate the self-induction in terms of the standard from the relation  $\frac{L}{L_1} = \frac{R + R'}{r}$ , and tabulate as follows—

NAME . . . . . DATE . . . . .  
 Alternator: Periods per Revolution  $K = \dots$   $p = \text{Zed.}$   
 Self-induction tested: Nature  $\sim \dots$

Speed of Alternator ( $N$ ) revs. per min.	Frequency $n = \frac{KN}{60}$ per sec.	Known Self-ind. $L$	Resistances.			Ratio $L/L_1$	Unknown Self-ind.	
			$R$	$R'$	$r$		$L_1$ seconds.	Mean $L_1$

(4) Repeat 2 and 3 for different values of  $L$ ,  $R$ ,  $R'$  and  $r$  at constant frequency ( $n$ ). Also for the former constant at different frequencies.

**Notes.**—When equal self-inductions are being compared it is found that the accuracy depends only on the sensitiveness of  $D$  to changes in  $(R + R')$ , and this instrument may be such that it detects differences or changes of 0.01%.

If it is noticed that increase of frequency causes a diminution of the resulting value of  $L_1$ , then the electrostatic capacity of the turns of the coils on one another is asserting itself and cannot be avoided. Considerable care should be taken to avoid this source of vitiation as much as possible, and also that due to heating of the conductors, etc. To minimize the former error, use short small wire leads, some distance apart, and not twisted twin lead.

### (129) Self-Inductions in Series and Parallel. Experimental Determination of Laws of Combination.

**Introduction.**—An electrical circuit may contain any or all of the three qualities—self-induction, capacity, and ohmic resistance. The last-named is always present, and may be combined with one or both of the former.

Let us suppose that no capacity is present, then the circuit, whether consisting of several distinct portions either in series or

parallel, or a combination of these, each having its own particular self-induction and ohmic resistance, possesses on the whole one definite effective value of induction and resistance, which may be termed the "*combined, equivalent, or effective*" self-induction and ohmic resistance of that circuit composed of such detailed portions.

In alternating current work it is of great importance to know the way in which various combinations of self-inductions and ohmic resistances will affect the working conditions of a circuit. The present test is devised with a view to elucidating these points for the three different forms of circuits or combinations, as follows—

- (a) The self-inductions and ohmic resistances in *simple series* only.

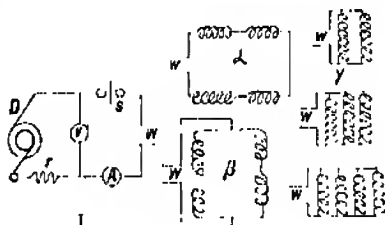


FIG. 135.

- (b) Self-inductions and resistances *partly in parallel and in series*.

- (c) " " " " *in parallel only*.

**Apparatus.**—Source of alternating current, preferably an independently driven alternator *D*, the exciting circuit (not shown) and the speed of which are under control; Siemens electro-dynamometer (Fig. 251) or Parr direct-reading alternating current ammeter *A* (p. 572); hot wire or electrostatic voltmeter *V*; non-inductive rheostat *r* (p. 598); switch *S*; speed indicator; four coils *A—D* to be experimented upon, as nearly alike as possible, and capable of being used with or without iron cores, which latter are also similar in all respects.

**Observations.**—(1) Connect up as in Fig. 135 I., and adjust the pointers of all the instruments to zero, levelling such as require it.

- (2) Connect coil *A* (only) to *W* (I.) and remove its iron core.



I. For pure series combinations such as (a) Fig. 135, show that

$$\frac{V}{A} = \sqrt{L_e^2 p^2 + R_e^2} = \sqrt{(L_1 + L_2 + L_3 + \dots)^2 p^2 + (R_1 + R_2 + R_3 + \dots)^2}$$

or generally that  $\frac{V}{A} = \sqrt{(\sum L)^2 p^2 + (\sum R)^2}$ , and therefore that the total effective self-induction  $L_e$  = sum of the individual self-inductions composing the circuit.

II. For series-parallel combinations such as (β) Fig. 135, show that

$$\begin{aligned} \frac{V}{A} &= \sqrt{L_e^2 p^2 + R_e^2} \\ &= \frac{\sqrt{(L_1 + L_2)^2 p^2 + (R_1 + R_2)^2} \sqrt{(L_3 + L_4)^2 p^2 + (R_3 + R_4)^2}}{\sqrt{(\sum L)^2 p^2 + (\sum R)^2}} \end{aligned}$$

III. For pure parallel combinations such as (γ) Fig. 135, show that

$$\frac{V}{A} = \sqrt{L_e^2 p^2 + R_e^2} = \sqrt{\frac{1}{\left(\sum \frac{L}{L^2}\right)^2 p^2 + \left(\sum \frac{R}{R^2}\right)^2}}$$

where  $L$  is the impedance of each parallel branch.

N.B.—In the present test it is assumed that the coils are incapable of having any mutually inductive action on one another, and consequently they must be arranged not to have such when making the test.

## The Electrostatic Capacity of Electrical Wires and Cables.

**General Remarks.**—The condition for obtaining an electrostatic capacity is the passage of a quantity of electricity into one of two conducting bodies which are separated by an insulator. Such an arrangement constitutes what is commonly termed an electrical condenser, the two conducting bodies being called the "coatings," and the separating insulator the "dielectric" of the condenser. Now it will be obvious that any insulated electrical wire or cable in contact with earth or its equivalent will form a condenser, the inner conductor or wire and earth being the two coatings, and the insulation of the cable the dielectric. In the case of an insulated cable possessing only one core, whether

consisting of one wire or a strand of wires, we shall obtain one particular definite capacity with a definite position of the cable. In other words, the capacity will depend on the geometrical form of the wire, so that if it was coiled up in a tank of water the capacity would not be the same as if it was laid out straight on the ground.

The actual value will depend in addition on the length and size of cable, and on the thickness of the insulation and its specific inductive capacity. The latest forms taken by cables, in which one conductor completely envelops another, but is insulated from it by a fairly uniform stratum of insulating material between the two, possess this property of having an electrostatic capacity in a more marked degree than the simple form mentioned above. Such a concentric cable, as it is termed, possesses a definite capacity per unit of length, and which is independent of how the cable is placed, i. e. whether coiled or straight. For continuous currents the capacity of cables or wires is of no practical importance, but for *intermittent or alternating currents* the case is otherwise. In submarine telegraphy the cable has naturally a very considerable capacity, while the current is intermittent; consequently when the circuit is closed so as to send a message, the cable has first to be charged by the sending battery before any current arrives at the receiving end for actuating the receiving appliances. This may take some seconds, depending on the length of cable, i. e. on its capacity. Thus the effect of capacity in such an instance is a detrimental one, giving rise to what is called "*inductive retardation*," and diminishing the speed of signalling. Here, in the above instance, we have the case of a single cable stranded conductor of which the copper core forms one coating, the iron sheathing and water the other.

With concentric cables, it has already been remarked that their capacity is greater than with single cables for equal lengths and section of conductors in the two cases; but the former possess the advantage that whereas the "outward" and "return" leads are very close together, in fact one encircling the other, their inductive action on telegraph and telephone wires in the vicinity is practically nil, as the external magnetic field produced is very small. This is of great value in alternating current distribution, for since the magnetic field produced by such currents alternates rapidly in



direction with the alternations of current, the inductive action of alternate current cables on such wires would otherwise be great. The capacity of a concentric cable can at once be calculated from the analogy to a cylindrical condenser as follows—

Assuming the two conductors to be both concentric and cylindrical, let  $R$  = radius of the inner surface of the outer conductor and  $r$  = radius of the outer surface of the inner one, and also let  $L$  = length of cable in centimetres. Then its capacity in farads—

$$C_s = \frac{2.413}{10^{12}} \times \frac{KL}{R - \log_{10} r}$$

where  $K$  = specific inductive capacity of the dielectric or insulating material, which for paper = 1.86 about, for india-rubber (pure) 2.34, vulcanized 2.94, for gutta-percha 4.2, and resin 2.55 about.

It may be noticed that since  $(\log_{10} R - \log_{10} r) = \log_{10} \frac{R}{r}$ , the units in which the radii are measured is quite immaterial, so long as the same is employed for each; the diameters  $D$  and  $d$  corresponding to  $R$  and  $r$ , may be used instead if we like, whence we shall have the

$$\text{Capacity} = \frac{2.413}{10^{12}} \times \frac{KL}{\log_{10} \frac{R}{r}} \text{ Farads} = \frac{2.413}{10^7} \times \frac{LK}{\log_{10} \frac{D}{d}} \text{ Microfarads}$$

reducing this to Mfd. per mile (statute) which = 160,933 cms.

$$\therefore \text{Capacity} = \frac{2.413 \times 160,933}{10^7} \times \frac{K}{\log_{10} \frac{D}{d}} = \frac{K}{25.75 \log_{10} \frac{D}{d}} \text{ Mfd. per mile.}$$

The capacity can readily be measured by means of the "method of mixtures" due to Lord Kelvin, and which is one of the best for the purpose. A complete digest of this and other kindred methods will be found in *Practical Electrical Testing*, p. 182, by the author, and they will not therefore be repeated here.

It may, however, be remarked that in testing the capacity of electric light and other cables by this method of mixtures the E.M.F. employed may conveniently be about 100 volts, and referring to Fig. 82, p. 184, of the above-mentioned work, the resistance  $ADH$  might be 100,000 ohms, and  $D$  connected to earth or tank if a single conductor cable is being tested. If it is a concentric cable this will not be immersed, and its two conductors at one end must be carefully insulated, while their other ends will form the two terminals of the capacity to be tested.

### (130) Measurement of the Electrostatic Capacity of Concentric—or Ordinary—Cables and Condensers. (Alternating Current Method.)

**Introduction.**—When an alternating-current E.M.F. is placed across a condenser or, say, a concentric cable, a certain measurable alternating current flows into the condenser or cable, even though in the latter the two conductors are quite free of all connections to lamps or any other appliances throughout their entire length. Moreover this current, which is called the "*capacity current*" of the cable, is not in phase or step with the periodic impressed E.M.F., but *leads* in advance of it, and constitutes what is called a *Wattless* or *idle current*, to distinguish it from the *load* or *useful* current which would flow in the cable when lamps or other appliances were switched on. In other words, it represents waste energy in the copper of the mains so far as the utility of the current is concerned, and the effect is always present with alternating currents. Thus it becomes of importance to know this idle or capacity current in order that its flow in the cable may not be mistaken for leakage current when no apparatus is connected to the cable.

It should also be noted that this current is out of step or phase with the main current.

The value of the capacity current in any cable can be deduced when certain constants are known. Thus—

Let  $A$  = virtual or  $\sqrt{\text{mean square value}}$  of the capacity current in amperes,

$V$  = virtual or  $\sqrt{\text{mean square value}}$  of the E.M.F. impressed in volts,

between the two conductors.

$C$  = capacity of the cable in farads,

and  $p = 2\pi n$  where  $n$  = frequency of the alternating current in periods (—) per second,

$$\text{then } A = \frac{V}{\frac{1}{Cp}} = CpV \text{ amperes,}$$

$\frac{1}{Cp}$  being the effective resistance to the passage of the current or reactance of the cable or condenser.

If  $C$  is in microfarads per mile and  $L$  = length of cable in miles,

$$\text{then } A = \frac{CLVp}{10^5} = \frac{2\pi nCLV}{10^5} \text{ amperes,}$$

$$\text{whence } C = \frac{10^5 A}{LV2\pi n} \text{ mfd. per mile.}$$

The present test is a very practical one and can nearly always be applied if the working pressure  $V$  is available.

**Apparatus.**—Cable or condenser to be tested ( $C$ ); either a Siemens electro-dynamometer, hot wire or Farr ammeter  $A$  (p. 577), each of which will correctly measure the  $\sqrt{(\text{mean})^2}$  value of the current; an electrostatic or hot wire voltmeter ( $V$ ), preferably the former; tachometer for measuring the speed of the alternator  $D$ , and from it deducing the value of ( $n$ ); switch  $S$ .

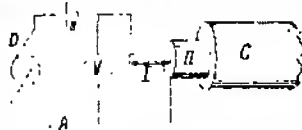


FIG. 136.

**Observations.**—(1) Connect up as shown in Fig. 136, and adjust the pointers of  $V$  and  $A$  to zero, carefully levelling them if necessary.

(2) Carefully “free” and insulate the far end of the cable, and prepare the near end so as to make contact with the two conductors  $I$  and  $II$ .

**Note.**—If a condenser is being tested  $I$  and  $II$  will now be its terminals.

(3) Close  $S$ , and with  $D$  running at constant speed take some six or eight widely different values of  $V$  by altering the excitation of  $D$ , and note the corresponding values of  $A$  simultaneously with  $V$ .

(4) Next run  $D$  at six or eight different speeds, keeping  $V$  constant by altering the excitation, and note the corresponding reading on  $A$  for each speed.

(5) Calculate the capacity tested from the relations—

$$C = \frac{10^5 A}{V2\pi n} \text{ mfd. for a condenser,}$$

$$C = \frac{10^9 A}{L \sqrt{2\pi n}} \text{ mfd. per mile for a cable,}$$

and tabulate as follows—

Name . . .					Data . . .		
Cable tested: Type . . .		Maker . . .		Size . . .	Insulation . .		
Condenser: Type . . .		Maker . . .		Dielectric . . .			
Length of Cable (L) miles.	Speed of Alternator.	Frequency (n) per sec.	Volts V.	Inductive Reactance $\frac{1}{C_p}$	Current.		Capacity of
					Reading on Instrument.	Amper. A.	Condenser in Mfd. Cable Mfd. per m.

### (131) Measurement of the Electrostatic Capacity of Short Lengths of Submarine and Electric Light Cables. (Kelvin Dead Beat Multicellular Voltmeter Method.)

**Introduction.**—The effects of electrostatic capacity in a cable on the intermittent or alternating currents flowing in it have already been mentioned (*vide* p. 373), consequently it is desirable to obtain the value of its capacity. The following is a convenient and accurate method of measuring the capacity of any insulated conductor comprising a short length of submarine, telephone, telegraph, or electric light cable, and its great advantage lies in the fact that it is applicable to short lengths.

The method, which is very analogous to the "Siemens subtraction method," except that only one deduction is made, consists in charging a standard known condenser to a measured potential and observing the fall of this on connecting the cable as a condenser in parallel with it. The condition for maximum accuracy, i.e. when a slight error in reading the diminished value of potential has least effect on the final result, has been shown to be when the standard capacity is equal to that of the unknown, or when the diminished potential = half the original value.

For accurate work it is necessary to employ two or three small corrections—one arising from the multicellular voltmeter

possessing a small capacity itself which varies with the deflection of the suspended needle vanes, being less for smaller deflections. It is of the order of about  $10^{-6}$  mfd., and in most cases can be neglected in comparison with the capacity of the standard and cable to be tested, at least when these are of the order of 0.01 mfd. or greater. When, however, extreme accuracy is required, the potential-capacity curve of the voltmeter, which is supplied by the makers, must be referred to, and the capacities of it, for the deflections obtained, taken into account.

Another correction is for loss of charge due to leakage occurring in the voltmeter, condenser, and cable; since during the time taken for the needle of the multicellular to come to rest after cutting off the battery or charging E.M.F. and putting the cable in parallel, the potential may have fallen owing to leakage.

It may therefore be necessary to determine the leakage of the voltmeter, cable, and condenser, which can be done as follows—

(a) Charge the voltmeter to some conveniently large potential, and take readings of *potential* and *time* after disconnecting the charging source. Then the curve plotted with potential as ordinates and time as abscissae shows the *rate of fall* of potential at any time after the disconnection of the charging source.

(b) Join the voltmeter and standard condenser in parallel, and repeat the preceding operations. Then the leakage from the condenser will be given at any time by the difference of the ordinates of the curves in a and b.

(c) Join the voltmeter and cable in parallel and again repeat. From these results leakage of the cable can be found at any time by subtracting the ordinates of the curves in a and c.

**Preparation of Cable Ends.**—The *free ends* of the cable should be bared of the outer insulation down to the pure rubber for a space of some  $2\frac{1}{2}$ " and the rubber itself pared or tapered with a clean sharp knife for a length of about  $1\frac{1}{2}$ " from the end; the ends should be carefully dried over a spirit lamp. One end should then be repeatedly painted with melted paraffin-wax (for some  $3\frac{1}{2}$ " from the end) heated to a temperature not exceeding  $100^{\circ}$  C. by means of boiling water. The other end of the cable after having a short well-insulated gutta-percha wire soldered to the copper core should be treated in a similar manner.

This method of preparation if carried out carefully will prevent all end leakage.

**Apparatus.**—Kelvin dead beat multicellular electrostatic voltmeter  $V$  (Fig. 240); Kolvin standard air leyden or condenser  $C$

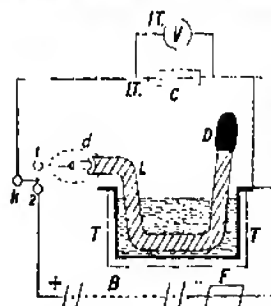


FIG. 137.

(p. 616); cable  $L$  to be tested immersed in a metal-lined water-tank  $T$ ; highly insulated two-way key  $K$  (p. 586); battery  $B$  giving an E.M.F. of something like 100 volts; and a fine fuse  $F$  to act as a safeguard in case of accidental short circuit in the condenser or voltmeter.

**Observations.**—(1) Carefully prepare the ends of the cable as indicated above and immerse the cable in the tank  $T$ , taking care not to allow the

prepared ends  $D$  and  $d$  to get wet; these must be trained up out of the water.

(2) Connect up as in Fig. 137, taking care that the insulated terminal  $I.T.$  of both  $V$  and  $C$  are joined as shown. Adjust the pointer of  $V$  to zero if necessary and see that a fine fuse is in  $F$ .

(3) Press  $K$  to 2 to charge  $V$  and  $C$ , and note the reading  $V_1$  on the voltmeter when steady and then release  $K$ . Now observe the reading for one or two minutes to see if there is any sensible loss due to imperfect insulation in  $V$  or  $C$ , and if so, whether it is small enough to neglect.

(4) Close  $K$  to 1, and in fifteen to twenty seconds, which is usually long enough, note the steady diminished reading  $V_2$  on the voltmeter.

(5) Repeat 3 and 4 with different charging E.M.F.s, and calculate the capacity of the cable  $L$  from the relation—

$$C_L = \frac{C_s(V_1 - V_2) + V_1 K_1 - V_2 K_2}{V_2} \text{ mfd.},$$

where  $C_s$  = standard capacity, in this case 0.0025 mfd., and  $K_1 K_2$  the capacities of the voltmeter at potentials  $V_1$  and  $V_2$ .

Name . . .

Date . . .

Standard Capacity: Type . . .

Capacity = . . . mfd.

Cable tested: Type . . . Length (ft) . . .

Insulation . . .

E.M.F. sent to Charge.	Volts per sec.		Capacity of Voltmeter.		Capacity of Cable.	
	Initial $V_1$ .	Final $V_2$ .	$K_1$ at $V_1$ .	$K_2$ at $V_2$ .	$C_L$ Mfd.	$\frac{C_L}{l}$ Mfd. per mile.

### (132) Measurement of the Electrostatic Capacity of a Concentric Cable Ballistically. (Standard Magneto Inductor Method.)

**Introduction.**—When some standard form of magneto inductor is available, the form devised by Dr. W. H. Hibbert being a very convenient and easily manipulated one, the capacity of a concentric cable or other electric light cable can be readily determined, providing a few other additional pieces of apparatus are available. The reader should note the general introductory remarks on p. 369 concerning the capacity of cables in general, and also those of the alternating current method of measuring the capacity of cables.

The present test can be employed for finding the capacity of cables in tanks and of ordinary and concentric mains. As, however, the former are best tested by the "method of mixtures" (p. 371), we shall here only consider the test of a concentric cable by this inductor method.

**Apparatus.**—Standard inductor to be tested  $I$  (Fig. 138); sensitive ballistic galvanometer  $G$ ; concentric cable to be tested  $C$ , of which  $F$  is the free and well-insulated end,  $S$

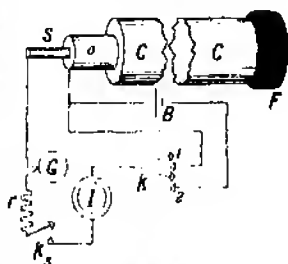


FIG. 138.

the inner conductor, and  $O$  the other; box of known resistances  $r$ ; battery  $B$ , of known E.M.F., or, if this is unknown, a standard voltmeter to measure the P.D.; two-way spring



tapping-key  $K$  (p. 586); ordinary spring tapping-key  $K_2$ ; damping-coil with its cell and key.

**Observations.**—(1) Connect up as in Fig. 138, and adjust the galvanometer needle to zero, carefully prepare the free (far) end of the cable, viz.  $F$ , in the manner described on p. 375, and also the (near) end as well; by so doing the vitiation of the results from leakage across the cable ends will be avoided.

(2)  $K1$  and  $K2$  being open, adjust  $r$  to a low value, such that pressing  $K_2$  nearly a full-scale throw  $d_1$  is obtained on slipping down  $I$ . Note this value of  $d_1$  and the box resistance  $r$  ohms.

(3)  $K_2$  being open, adjust the voltage of the battery  $B$  to such a value that on closing  $K2$  for two or three seconds, then opening it, and immediately closing  $K1$ , a first throw  $d_C$  is obtained on discharging  $C$ , as nearly as possible equal to the former.

N.B.—Two or three throws should be taken in both 2 and 3, and the means noted as being more accurate.

(4) Obtain the mean throw on the charge in a similar way by first closing  $K1$  for a few seconds so as to completely discharge  $C$ , and then opening it and closing  $K2$  afterwards.

**Note.**—Care must be taken that  $C$  is each time discharged *before* taking the charge throw.

(5) If possible employ three or four different voltages and repeat 2 and 3 with each of them, keeping the deflections  $d_1$  and  $d_C$  about equal to one another, preferably by varying  $r$  to suit.

(6) Calculate the capacity of the cable tested from the relation

$$C = \frac{FN}{100 VR} \cdot \frac{d_C}{d_1} \text{ microfarads,}$$

where  $F$  = total magnetic flux in the air-gap of the inductor and

$R$  = total resistance in ohms of the inductor circuit.

Tabulate as follows—

Name . . .

Date . . .

Standard inductor . . . ; turns  $N$  = . . . ; resistance  $r_R$  = . . . ohms.

Galvanometer resistance  $G$  = . . . ohms; Total flux  $F$  = . . . C.G.S. lines.

Cable tested: Type . . . Maker . . .

Length of Cable  $l$  = . . . miles. Section (for reference only) = . . . sq. ins.

Mean first throw.		Resistance in Ohms.		P.D. $V$ variable $V$ .	Capacity to Microfarads $C$ .	Mean Capacity $C$ .	Capacity of Cable in Mfd. per mile $C/L$ .
$d_1$ .	$d_C$ .	In box $r$ .	Total $R = r + r_R + G$ .				

**Inferences.**—Show how the relation given in 6 can be obtained, and state any assumptions made in obtaining it. Is any correction required for greater accuracy in the relation for  $C$ ?

### (133) Measurement of the Electrical Power absorbed in Alternating Current Inductive Circuits. (Three-voltmeter Method.)

**Introduction.**—The measurement of alternating current power depends on the nature of the external circuit. Thus, if this circuit is *non-inductive*, then the true power  $W = \text{amps. } (A) \times \text{volts } (V)$ , the former flowing in the external circuit at a terminal potential difference  $(V)$ .

If the circuit is inductive, and every circuit is to some slight degree, then  $W = AV \cos \theta$ , where  $\theta =$  angle of phase difference of the current  $A$  behind the voltage  $V$  and the product  $(A \times V)$  is called the *apparent power* absorbed.

The measurement, therefore, of this electrical power accurately is more difficult than that in the case of a direct current circuit, owing to the effects of self and mutual induction and capacity which appear in alternate-current (A.-C.) working. In such a case a Wattmeter may be used, but it must be practically non-inductive to give accurate results. Another method to employ, which will give accurate results even though most of the circuit is highly inductive, is that known as the "*three-voltmeter method*," and it has the advantage that only one A.-C. voltmeter is required, though three similar ones may be used if available. By it the *true power* absorbed by the circuit may be obtained with any degree of accuracy desired by using an accurately graduated voltmeter, and by carefully repeating the readings two or three times and noting the mean in each case.

The three-voltmeter method, which was simultaneously suggested by Prof. Ayrton, Dr. Snipner and Mr. Swinburn, gives a true measure of the power given by any current, whether harmonic or otherwise, to any circuit, inductive or not. It has the disadvantage that, as the differences of squares of quantities is being taken, a small error in the quantities themselves may make a considerable error in the final result, especially if the angle of lag  $\theta$  is large.



between the current ( $A$ ) and total voltage  $V$ , while  $\theta_1$  will be that between  $A$  and the voltage  $V_1$ .

**Note.**—Errors in  $V$ ,  $V_1$  or  $V_2$  or in the graduation of the voltmeter scale, will have least effect on the result when  $V_2 = V_1$ , which is the condition for maximum accuracy, and the resistance  $r$  of  $QR$  should first be adjusted if possible to obtain this condition.

Should the non-inductive resistance  $QR$  not be accurately known, or be likely to alter in value through heating due to the passage of the current  $A$ , then its equivalent in terms of  $V_2$  and  $A$  can be substituted in the formula. Hence, if  $A$  is the  $\sqrt{\text{mean square}}$  current in amps as given by a Siemens dynamometer or other direct reading alternating current ammeter, we shall have

$$W = \frac{A}{2V_2} \{ V^2 - V_1^2 + V_2^2 \} \text{ Watts,}$$

for the true mean power given to the whole circuit  $PR$ ,  $QR$  may consist of a bank of electric glow-lamps, as the resistance  $r$  of  $QR$  can vary if it likes with the different mean currents.

It can easily be shown, in like manner, that the true mean power given to the inductive portion  $PQ$  of the circuit is

$$W = \frac{1}{2r} \{ V^2 - V_1^2 - V_2^2 \} = \frac{A}{2V_2} \{ V^2 - V_1^2 - V_2^2 \}$$

The method is not based on any assumptions as to the nature of the current (whether periodic or otherwise) or of the circuit, which may contain either self or mutual induction, and capacity, or all three. It is based solely on the difference in phase between the current and voltage.

If  $\theta$  = angle of phase difference or lag of the current behind the voltage, then if both are sine functions

$$\cos \theta = \frac{V^2 - V_1^2 - V_2^2}{2V_1V_2}$$

**Apparatus.**—Alternator  $D$  and its exciting circuit; inductive portion  $PQ$  of the circuit in series with a strictly non-inductive portion  $QR$ ; two 2-way keys ( $K_1$  and  $K_2$ ) (p. 587); an A.C. voltmeter ( $V$ ); main switch ( $S$ ); A.C. ammeter ( $A$ ). For comparison of methods,  $A$  may be used, and also a non-inductive Wattmeter  $W$  for measuring directly the power used up in  $PR$ . Frequency meter  $f$  connected across the supply  $D$ .

In the electrical circuit of the motor  $M$  may be used a volt. meter  $V_2$ ; ammeter  $a_2$ ; switch  $S_2$ ; rheostat  $R_2$ ; source of continuous current  $E$ .

**Experiments.**—(1) Connect up as shown in Fig. 140. Adjust the pointer of all the instruments to zero, levelling such as need it.

(2) See that all lubricators in use feed properly, then start  $D$ , running slowly.

(3) Adjust its speed so as to get  $\frac{1}{2}$  of the max.  $\sim$  per sec., at the same time varying the excitation of  $D$  to alter its voltage ( $V$ ), so

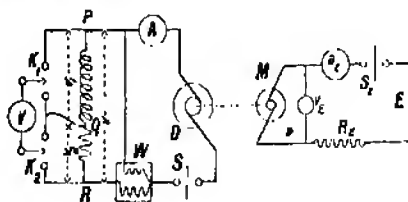


FIG. 140.

as to send a convenient current ( $A$ ) through  $PQ$ . Note  $A$ , and in quick succession (the speed being constant) the voltages  $V$ ,  $V_1$  and  $V_2$ , across  $PR$ ,  $PQ$ , and  $QR$ . (See Note above.)

(4) Repeat 3 for about 5 frequencies between the max. and min. values possible, using the *same current*  $A$  in each case by suitably altering the excitation.

(5) Repeat 3 at a *constant frequency* of about normal for five different current values, rising by equal increments up to the maximum allowed, by varying the excitation.

Tabulate your results as follows—

Fonr. of Inductive Circuit  $PQ$  teste\*  
 „ Non-Iml. resistance  $QJ$  used . . .

ft Frequency s ^	Voltage CB.			Power in Watts absorbed in			Power Factor.		From Mittl. Tub'es		Ohmic lies.		*  5
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(G) Plot curves having values of  $A$  as abscissas with values of  $r_{if} \cos \theta_X$ ,  $X$ ,  $\frac{y}{A}$  and  $w_u$  respectively, for the inductive portion  $PQ$  as ordinates.

(7) Draw the vector diagram (Fig. 139) for the maximum current used.

(8) Compare  $V$  with the algebraical sum ( $\vee$ - $V_2$ ), also  $W$  with  $w$ .

**Inferences.**—Prove the formula in column 7, and state any assumptions made in deducing it. What can be inferred from the results of the test and from the curves?

**(134) Measurement of the Electrical Power absorbed in Alternating Current Inductive Circuits. (Three-Ammeter Method.)**

**Introduction.**—This method, though inferior to that of the Wattmeter, is nevertheless instructive, and therefore a brief *reminiscence* of it will be given here. As will be seen, it is very similar to the 3-voltmeter method of measuring power, the formulæ in the two cases being strikingly similar. There is, however, one chief difference between the methods, namely, that practically three ammeters are necessary for a satisfactory test, as large errors

may occur if only one ammeter is employed and interchanged between the circuits, while in the case of the allied method one voltmeter can easily be made to do and no appreciable error need be introduced. The actual arrangement is shown in Fig. 141, in which  $PQ$  represents the circuit in which it is desired to measure the power taken up,  $A$ ,  $A_1$  and  $A_2$  are three non-inductive ammeters, at least  $A_1$  should be of this nature, while ( $r$ ) is a non-inductive resistance connected as shown, and which is large

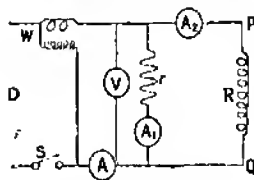


FIG. 141.

compared with that of  $A_1$ . Greatest accuracy will be obtained when  $A_1 = A_2$ , and under these conditions it will be seen that ( $r$ ) consumes about as much power as  $Q$ . Hence twice as much power has to be available at the source for operating this method as is taken up in

$PQ$ , but practically no excess voltage is needed in this case as it was in the 3-voltmeter method. If  $w_1$  = the power in Watts absorbed by  $PQ$ , then

$$w_1 = \frac{1}{2}r\{A^2 - A_1^2 - A_2^2\}$$

and

$$\cos. \theta_1 = \frac{A^2 - A_1^2 - A_2^2}{2A_1A_2}$$

where  $\theta_1$  = angle of lag of the current  $A_2$  in the inductive circuit  $PQ$  behind the terminal voltage.

It will thus be seen that the method is based on the difference of phase of the various currents, and, as in the 3-voltmeter method, a small error in observing the currents introduces large errors in the answer. The possibility of such occurring can be minimized by using accurately calibrated non-inductive ammeters and taking the mean of three or four similar readings at each value of, say,  $A$ . If the value of non-inductive resistance ( $r$ ) is not accurately known, or if it is liable to alter through heating due to the passage of the current, then its equivalent value  $\frac{V}{A_1}$  may be used instead in the formula, which will therefore become —

$$W = \frac{V}{2A_1} (A^2 - A_1^2 - A_2^2) \text{ Watts,}$$





voltage  $V$  is  $\alpha$ . The angle of phase difference between the main current  $A$  and  $V$  will be  $\theta$ , and that between  $A_2$  and the same voltage  $V$  across  $PQ$  will be  $\theta_1$ .

From the geometry of Fig. 112 we see that

$$A_2^2 = A^2 + A_1^2 - 2AA_1 \cos \theta,$$

but  $A_1 = \frac{V}{r}$  by Ohm's law, and

$$\therefore A_2^2 = A^2 + A_1^2 - 2A \frac{V}{r} \cos \theta,$$

and  $AV \cos \theta$  = total power given to the whole parallel circuit.

$\therefore$  the total power absorbed in the whole circuit is

$$w = V \times \alpha = \frac{r}{2}(A^2 + A_1^2 - A_2^2) \text{ watts,}$$

the power absorbed in the non-inductive branch

$$w_1 = A_1^2 r = A_1 V \text{ watts,}$$

and the power absorbed in the inductive branch

$$w_2 = V \times bc = \frac{r}{2}(A^2 - A_1^2 - A_2^2) \text{ watts,}$$

where the power factor for the whole circuit =

$$\cos \theta = \frac{A^2 + A_1^2 - A_2^2}{2AA_1} = \frac{r(A^2 + A_1^2 - A_2^2)}{2AV},$$

and the power factor for the inductive circuit  $PQ$  =

$$\cos \theta_1 = \frac{A^2 - A_1^2 - A_2^2}{2A_1A_2} = \frac{r(A^2 - A_1^2 - A_2^2)}{2VA_2}.$$

In this three-ammeter method the non-inductive parallel branch is equivalent to an *added current*, while in the three-voltmeter method the non-inductive series resistance means an *added voltage*. Both methods, therefore, require the supply of practically twice as much power as that needed for the circuit under test. Further, the losses in the ammeters, voltmeter, and wattmeter may cause serious errors in the results if the currents are small. For the above reasons, no one would use either method for measuring power if a wattmeter was available, except from a purely scientific interest. While the power absorbed and phase difference may be calculated in each method from the vector diagram, constructed for each set of readings, it would usually be obtained from the respective formulae.

**Apparatus.**—That indicated in Fig. 141, where  $D$  is an adjustable source of alternating current, preferably a motor-driven alternator, the frequency, current and voltage of which can be

varied independently. A voltmeter  $V$  is connected across the parallel combination, and a wattmeter inserted so as to measure the total watts absorbed in the parallel combination merely for the comparison of the three-ammeter and wattmeter methods.

**Observations**—(1) Connect up as in Fig. 141, levelling and adjusting to zero such of the instruments as need it.

(2) See that all lubricating arrangements are in operation on starting up.

(3) Adjust the speed to get maximum frequency, and also the voltage  $V$  of the alternator (by varying its excitation) so as to send the maximum safe current  $A_2$  through  $PQ$ , and note in rapid succession the readings of  $A_1$ ,  $A_2$ ,  $W$  and  $V$ .

**Note**.—If possible adjust the non-inductive resistance  $r$  so as to obtain the conditions for maximum accuracy (other things being the same) of  $A_1 = A_2$ .

(4) Repeat (3) for about six different frequencies between the maximum and minimum values possible, using the same current  $A_2$  in each case by suitably adjusting the speed and excitation of the alternator.

(5) Repeat (3) at constant maximum frequency for about six different values of current  $A_2$  between the maximum and minimum values possible by varying the excitation, and tabulate your results as follows—

Form of Inductive Circuit  $PQ$  tested . . .  
Non-ind. Resistance used . . .

Frequency of Supply $f$	Currents			Power in Watts absorbed in		Power Factor in	From Math. Tables	Rec. of		Impedance of Parallel Combination $\pm jL$
	$A_1$	$A_2$	Wattmeter $W$	$PQ$ $+ r$	$PQ$ $+ r$	$PQ$ $+ r$	Angle of Lag in	$r$	$PQ$	
			$W = A_1 V$	$PQ$	$(PQ + r)$ By Calcul. ation.	$PQ$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$W = \frac{P}{2A_1}$	$0^\circ$	$\tan \theta_1$		
			$W = A_1 V$	$W = \frac{P}{2A_1}$						

(6) Plot curves having values of  $A_2$  as abscissae with values of  $V_1 \cos \theta_1$ ,  $L$ ,  $\frac{V}{A_1}$  and  $w_p$ , respectively, for the inductive portion  $PQ$  as ordinates.

(7) Draw the vector diagram (Fig. 142), for the maximum current used.

(8) Compare the value of  $A$  with the algebraical sum  $A_2 + A_1$ ; also  $W$  with  $w$ .

**Inferences.**—What can you infer from the results of the test and from the curves?

### (135) Measurement of Power in Three-Phase Alternating Current Circuits.

**Introduction.**—The measurement of the electrical power absorbed in a 3-phase alternating current circuit might well at first sight appear somewhat complicated. In reality, however, it is very little more so than in the case of single-phase circuits and the actual extent to which it is, depends mainly on the nature of the circuit in which the measurement is being made. It has already been seen that the non-inductive Wattmeter forms the best means of obtaining the *true power* absorbed in a single-phase circuit, but with multiphase circuits usually, though not always, two such instruments are necessary.

The object consequently of the present investigation is not only to state the methods of measuring, but also to prove the truth of them under the several distinctive conditions met with in practice.

The circuit in which the power has to be measured may be of the type shown at (a) Fig. 141, which is known as the *star* or *open* form, or of the type shown at (b) Fig. 143, known as the *mesh* or *closed* form. (c) represents the circuit containing the measuring instruments, which may be connected to either (a) or (b) arrangements at will,  $E$  being the source of polyphase supply.

Now let  $A_1$ ,  $A_2$ ,  $A_3$  and  $a_1$ ,  $a_2$ ,  $a_3$  be the  $\sqrt{\text{mean square}}$  values of the currents flowing in the mains and branches respectively for Fig. 143 (b and c), also  $V_1$ ,  $V_2$ ,  $V_3$  and  $v_1$ ,  $v_2$ ,  $v_3$  the same values of voltages across the mains and branches respectively for Fig. 143 (b and c); then if the mains are equally loaded we have—

$$A_1 = A_2 = A_3, \text{ and } \therefore a_1 = a_2 = a_3, \text{ and } V_1 = V_2 = V_3,$$

whence  $A_1 = 2a_1 \sin. 60^\circ = \sqrt{3}a_1$ , and  $\therefore A = \sqrt{3}a$ , since the mains are equally loaded and the load non-inductive.

For Fig. 143 (a and c) we have, if  $A_1 = A_2 = A$ , and  $E_1 = E_2 = E$ , that  $A_1 = a_1$ ,  $A_2 = a_2$  and  $A_3 = a_3$ , and since  $V$  will now lag  $30^\circ$  in phase behind  $r$ , in each main and the corresponding branch circuit, we have  $V = 2r \sin. 60^\circ = \sqrt{3}r$ , providing the load is non-inductive.

CIRCUITS EQUALLY LOADED AND NON-INDUCTIVE.—Here if each main carries the same current  $A$ , and if the pressure between

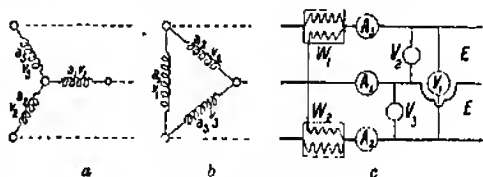


FIG. 143.

each pair of mains  $= V$ , then the True Power absorbed in a non-inductive load, Fig. (b)

$$W = 3ar = 3V \frac{A}{\sqrt{3}} = \sqrt{3}AV \text{ Watts,}$$

True Power absorbed in a non-inductive load, Fig. (a)

$$W = 3ar = 3A \frac{V}{\sqrt{3}} = \sqrt{3}AV \text{ Watts.}$$

If, however, the load is inductive, then if  $\theta$  = angle of phase difference between voltage and current, we have, as in the case of single-phase work, that for equal load the True Power absorbed in the inductive load, Figs. (a) or (b)

$$W = \sqrt{3}AV \cos. \theta \text{ Watts.}$$

This latter can best be obtained by means of the non-inductive Wattmeter for each of the two following conditions met with in practice.

CIRCUITS EQUALLY LOADED AND INDUCTIVE.—ONE WATTMETER ONLY needed to obtain the true power. Assuming this to be  $W_1$ , Fig. 143 (ca) or (cb), then with the thick coil in any main ( $A_2$  say, as shown) note the Wattmeter reading ( $w_1$ ) with its fine coil on

to main  $A_1$ , and the reading ( $w_2$ ) with it on to main  $A_2$  immediately after, then the True Power absorbed in the *equally loaded inductive circuit*  $W = w_1 \pm w_2$ , where both  $w_1$  and  $w_2$  will vary with load and power factor.

The reason why  $w_1$  or  $w_2$  alone does not give the power of the circuit is because  $A_3$  and  $V_2$  are not in phase, even in a non-inductive circuit, but differ in phase by an angle  $= 30^\circ \pm \phi$ , for both star and mesh connections. Therefore  $W_1$  will read the

product  $A_3 V_2 \cos 30^\circ = \frac{\sqrt{3}}{2} A_3 V_2$  for unity power factor. Thus

we see that  $w_1 = A_3 V_2 \cos (30^\circ + \phi)$ , and  $w_2 = A_3 V_2 \cos (30^\circ - \phi)$ , and the sum of these after expansion  $= 2A_3 V_2 (\cos 30^\circ \cos \phi) = \sqrt{3} A_3 V_2 \cos \phi = w_1 + w_2$ , which is the true power in the circuit. If now the load is so highly inductive that  $\phi$  exceeds  $60^\circ$ , i.e. the power factor  $\cos \phi$  is less than 0.5, then  $\cos (30^\circ + \phi)$  becomes  $-ve$ , and the wattmeter will reverse for one of its readings  $w_1$  or  $w_2$ , which must therefore be considered as  $-ve$  since the volt-coil connection must be reversed to get a scale reading.

$\therefore$  the total power  $W = w_1 - w_2 = 2A_3 V_2 \sin 30^\circ \sin \phi$   
 $= 2A_3 V_2 \times \frac{1}{2} \sin \phi = V_2 \times A_3 \sin \phi$ , and  $V_2 \times \frac{A_3 \sin \phi}{\frac{1}{2}}$   
 $= A_3 \sin \phi =$  the wattless or idle line current.

The above results will be readily understood by a reference to Fig. 144 (corresponding to Fig. 143, *a* and *c*), in which  $OA$ ,  $OB$ ,  $OC$ , represents the voltages across the respective star stator phase windings in magnitude and phase difference ( $= 120^\circ$ ).  $AC$ ,  $CB$ ,  $BA =$  voltages  $V_1$ ,  $V_2$ ,  $V_3$  between mains in relative magnitude and phase ( $= 120^\circ$ ).

Then obviously  $V_1 = AC = \sqrt{3}OA = \sqrt{3}OC$ ,

also  $V_2 = CB = \sqrt{3}OC = \sqrt{3}OB$ ,

and  $V_3 = BA = \sqrt{3}OB = \sqrt{3}OA$ .

Now, since the three phase-windings are inductive we can draw three equal lines,  $Oa$ ,  $Ob$ ,  $Oc$ , to represent the currents in them lagging in phase by equal angles  $\theta$  behind their respective voltages  $OA$ ,  $OB$ ,  $OC$ .

Then the current  $Oa$  in its phase winding differs in phase from the voltage  $AB (= V_2)$  by an angle  $aDA = \theta - 30^\circ$ , and the

current  $Ob$  in its phase winding differs in phase from the voltage  $BC$  ( $= V_2$ ) by an angle  $Ocb = \theta + 30^\circ$ .

Now, if the current coil of wattmeter  $w_1$  is in the circuit of  $OC$ , and hence of main 3, with its volt coil across  $CB$  (mains 3 and 1), it will carry the current  $Oc$  at a voltage  $V_3$ . Similarly the current coil of wattmeter  $w_2$  in the circuit of  $OA$ , and hence

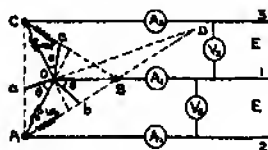


FIG. 114.

of main 2, will carry the current  $Oa$  with its volt coil across  $AB$  (mains 2 and 1) at a voltage  $V_3$ .

$$\begin{aligned} w_1 &= A_3 V_2 \cos (\theta + 30^\circ), \\ &= A_3 V_2 (\cos \theta \cos 30^\circ - \sin \theta \sin 30^\circ), \end{aligned}$$

$$\begin{aligned} \text{and } w_2 &= A_2 V_3 \cos (\theta - 30^\circ) \\ &= A_2 V_3 (\cos \theta \cos 30^\circ + \sin \theta \sin 30^\circ). \end{aligned}$$

$\therefore$  total power of the circuit  $W = w_1 + w_2 = 2AV (\cos \theta \cos 30^\circ) = \sqrt{3}AV \cos \theta$ , on the assumption that  $A_1 = A_2 = A_3 = A$ , and  $V_1 = V_2 = V_3 = V$ , which should be the case.

By adding and subtracting the values of  $w_1$  and  $w_2$  first given we have

$$\frac{w_1 - w_2}{w_1 + w_2} = \frac{1}{\sqrt{3}} \tan \theta, \quad \text{and putting } \frac{w_2}{w_1} = a$$

we have the power factor

$$\cos \theta = \frac{a + 1}{2\sqrt{a^2 - a + 1}} = \frac{1}{\sqrt{1 + 3\left(\frac{w_1 - w_2}{w_1 + w_2}\right)^2}} \quad (\text{see p. 399}),$$

when  $\theta = 0$  the values of  $w_1$  and  $w_2$  are equal, and each  $= \frac{1}{2} \sqrt{3}AV \cos \theta$ .

As  $\theta$  increases,  $w_1$  decreases and  $w_2$  increases, when  $\theta = 30^\circ$  the value of  $w_1 = \frac{1}{2} A_2 V_2$  or  $\frac{1}{2} AV$ , and of  $w_2 = A_1 V_3$  or  $AV$ ; when  $\theta = 60^\circ$  the value of  $w_1 = 0$ , and of

$$w_2 = \frac{\sqrt{3}}{2} A_2 V_2 \text{ or } \frac{\sqrt{3}}{2} AV.$$

Since in this case the current in the series coil of  $w_1$  differs  $90^\circ$  in phase from that in its pressure coil, any further increase in  $\theta$  will make  $w_1$  negative and reverse its deflection, so that the connections of one of its coils must be interchanged in order to bring the deflection on to the scale again.

Hence in measuring the power of any inductive 3-phase circuit by either 1 or 2 wattmeters the total power  $= w_1 \pm w_2$ , i. e. if one of the readings reverses, subtract the smaller reading from the larger one to obtain the total power.

**CIRCUITS UNEQUALLY LOADED AND INDUCTIVE**—Two **WATTMETERS ONLY** needed to obtain the true power. Assuming the Wattmeters to have their thick coils in any two mains, as shown in Fig. 143 (*a* or *b*), then True Power absorbed  $W = W_1 + W_2$ .

Hence, when merely the true power in Watts only is required in a three-phase circuit, whether of the *star* or *mesh* type, one or two Wattmeters are required according to whether the circuits are *equally* or *unequally loaded* respectively. Also when such a three-phase circuit is both equally loaded and non-inductive the true power in Watts is given by the product  $\sqrt{3} \times \text{amps. in one main} \times \text{volts across any pair of mains}$ . (See p. 395 *et seq.*)

**Apparatus.**—Source of three-phase alternating current (*K*) and circuit of variable nature to experiment upon (*a* and *b*, Fig. 143).

Two Wattmeters  $W_1$  and  $W_2$ ; three Siemens dynamometer or Parr direct reading dynamometer ammeters  $A_1 A_2 A_3$ ; three electrostatic or hot-wire voltmeters  $V_1 V_2 V_3$ .

**Note.**—It must be remembered that for any specific measurement, the foregoing rules, and the instruments they entail, can be at once used without reference to the following test, which is devised solely in order to prove these rules.

**Observations.**—(1) Connect up as in Fig. 143 (*a* and *c*), and adjust the instruments to zero, levelling them if necessary.

(2) With the *load non-inductive* and the *circuits equally loaded*, take the readings of all the instruments for five or six different loads, noting the Wattmeter reading when placing the fine coil of, say,  $W_1$  successively on to  $A_1$  and  $A_2$  mains at each load.

(3) With an inductive load and circuits equally loaded, take the readings of all the instruments for five or six loads, placing the fine coil of, say,  $W_1$  successively on to  $A_1$  and  $A_2$  mains at each load and noting its reading at each. Tabulate your results as follows—

Nature of Circuit	Loading of Circuit	Wattmeters.		Voltmeters.			Ammeters.			$W = W_1 + W_2$	$W = \frac{1}{2} W_1$	$P = \sqrt{3} E I$
		$W_1$	$W_2$	$V_1$	$V_2$	$V_3$	$A_1$	$A_2$	$A_3$			

**Inferences.**—State very clearly all that can be inferred from your experimental results.

### Measurement of Power in Two-Phase Alternating Current Circuits.

**Introduction.**—Two distinct forms of circuits are met with in the distribution of electrical energy by means of two-phase alternating currents of electricity.

The first entails the use of four wires, forming two circuits completely independent of one another, one to each phase. Since this requires four wires it is usually employed in short distance transmissions.

The second entails the use of only three main wires, and is therefore more economical in first outlay of copper than the above. It will therefore be at once obvious that the measurement of power in two-phase alternating current circuits will be made in more than one way, depending on the form and nature of the circuit in question. We will now deal with such measurements in the case of each possible condition.

#### TWO-PHASE CIRCUITS OF THE 4-WIRE FORM.

Here two cases are possible according to whether the circuits are carrying non-inductive loads, such as incandescent lamps, or inductive loads, such as two-phase motors or transformers, etc.

**Non-inductive load.**—The product of the amperes and volts in each circuit, obtained in the usual way, when added together gives the true power delivered from the generator; and if the two circuits are equally loaded, *twice* the product for one circuit gives the Total True Power.

**Inductive load.**—Owing to the lag in phase between the current and voltage in each circuit, two non-inductive Wattmeters are necessary, one in each circuit, connected up in the ordinary way



as in single-phase circuits. Then the Total True Power delivered by the generator = sum of the two Wattmeter readings.

If the two circuits are equally loaded, as should be the case when supplying such as two-phase motors, then twice the reading of one Wattmeter gives the Total True Power, and only one such instrument is then necessary.

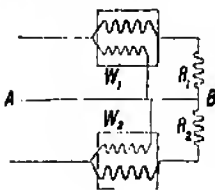


FIG. 145.

#### TWO-PHASE CIRCUITS OF THE 3-WIRE FORM.

Here also there are two or three cases depending on whether the circuits are inductive or otherwise.

*Equally loaded non-inductive sections.*—Total True Power absorbed = twice the product of the current in one outer main and the voltage across the section.

*Equally loaded inductive sections.*—Total True Power absorbed = twice the reading of a Wattmeter connected with its thick coil in series with either outer main, and its thin coil connected to the centre or larger main which is common to both outers.

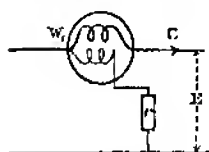
*Unequally loaded inductive sections.*—Total True Power absorbed = sum of the two readings of the Wattmeters connected with their thick coils in the outers respectively, and their thin coils connected to the common centre wire  $AB$  as shown in Fig. 145. This last case would be the one met with when the circuit was partly a lighting and partly a power one, running two-phase motors.

Where the reader may not be quite conversant with the preceding methods of measuring power in two-phase alternating current circuits, a most useful experiment will be to prove the above statements in much the same manner as was set forth in the preceding test on three phase measurements of power, only three or four ammeters and voltmeters with the two Wattmeters  $W_1$  and  $W_2$  and the variable two-phase rheostat being required.

## Measurement of Power in Polyphase Alternating Current Circuits.

As a summary, with some additions, to the methods as given on pages 388-394, the principal arrangements of wattmeters employed for measuring the true power in different kinds of alternating current circuits commonly met with in practice, are given here in diagrammatic form.

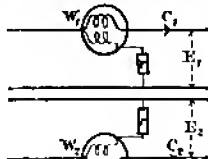
SINGLE PHASE



$$W_1 = EC \cos \phi$$

$$W = W_1$$

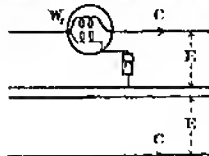
FIG. 146.

TWO PHASE (UNBALANCED)  
INDEPENDENT OR COMMON RETURN

$$W_1 = E_1 C_1 \cos \phi \quad W_2 = E_2 C_2 \cos \phi$$

$$W = W_1 + W_2$$

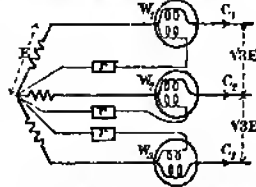
FIG. 147.

TWO PHASE (BALANCED)  
INDEPENDENT OR COMMON RETURN

$$W_1 = E C \cos \phi$$

$$W = 2 W_1$$

FIG. 148.

THREE PHASE (UNBALANCED)  
USING THREE INSTRUMENTS

$$W_1 = E_1 C_1 \cos \phi \quad W_2 = E_2 C_2 \cos \phi \quad W_3 = E_3 C_3 \cos \phi$$

$$W = W_1 + W_2 + W_3$$

FIG. 149.

$W$  = the total watts in the system.

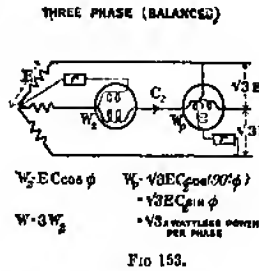
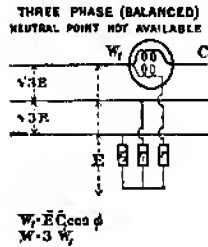
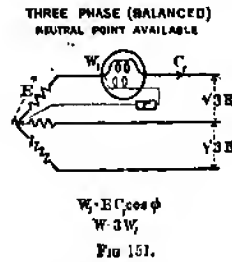
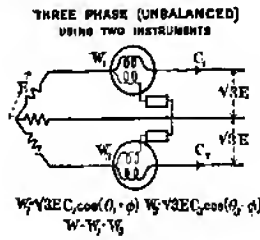
$W_1, W_2, W_3$  = readings of the various wattmeters.

$E, E_1, E_2$  = voltages " " " sections.

$C, C_1, C_2, C_3$  = currents in " " "

$r_1, r_2, r_3$  = the non-inductive resistances in series with the fine wire coils of the wattmeters,  
 $\phi_1, \phi_2, \phi_3$  = angles of phase difference between currents and voltages.

The diagrams and deductions accompanying each explain the principle clearly enough.



In Fig. 150, if the power factor of the system is less than 0.5, one of the wattmeters will read negatively and the connections of its fine wire circuit will have to be interchanged in order to obtain deflections on the scale. In this case the *difference of the two wattmeter readings gives the total power*.

In Fig. 152, the resistances  $r_1 = r_2 = (r + \text{fine wire coil})$ , but an artificial neutral point can be formed by lamps without the expense of the resistances  $r_1, r_2$ .

In Fig. 156, unless the resistance of the fixed current coil is

small compared with the resistance of the phase in series with which it is connected, its insertion will throw out the balance of a mesh system and  $3W_1$  will not = the total true power. The

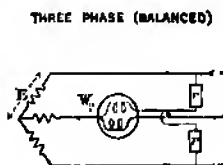


FIG. 154.

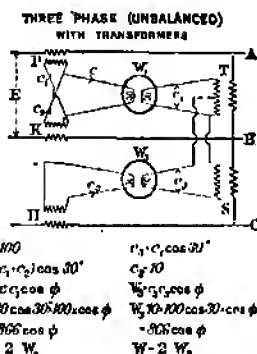


FIG. 155.

arrangement in Fig. 150, or if the system is balanced one wattmeter with a two-way key for connecting one end of the fine

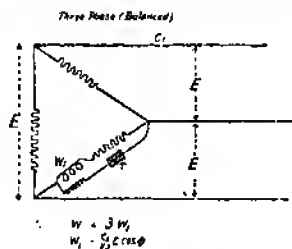


FIG. 156.

wire coil in quick succession to the remaining two mains, is much to be preferred.

Fig. 155 shows a method of connecting two wattmeters in three-phase high tension mains  $ABC$  using current and pressure

transformers. *P* and *K* are two 20 to 1 series transformers, giving a secondary current of 5 amps. at full load; while *H* is a 10 to 1 series transformer, giving a secondary current of 1 amp. at full load. *T* and *S* are each 100 to 1 pressure transformers, with 10,000 volts on the primaries. It can be shown

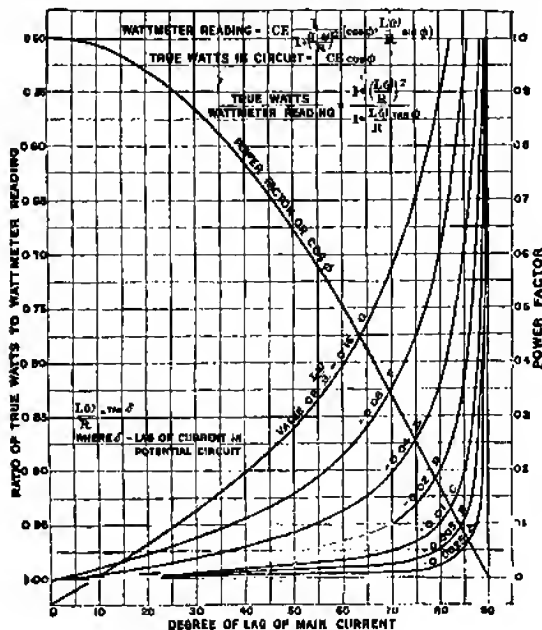


FIG 157.

that each wattmeter indicates 866 kw. at full load, the total power of the circuit being 1732 kw.

**Note.**—The above methods are equally applicable to measuring the output of a generator or input into a motor or rheostats.

The measurement of power factor in alternating current circuits can be made by means of power factor indicating

instruments, or by the method described on page 358, in the case of three-phase circuits. Another method is shown in Fig. 153 for three-phase circuits in which a wattmeter  $W_r$  connected as shown indicates the wattless power in a phase, or the power factor, if the scale be suitably graduated. The instrument in this case has a central zero and deflects to one side or the other according to whether the current lags or leads with respect to voltage.

As with such an arrangement, a considerable P.D. will exist between the fixed and moving coils, it can only be recommended for the lower voltages.

Another and safer method can be employed with balanced three-phase circuits using one wattmeter in one main and a two-way key for connecting one end of its fine wire circuit in quick succession to the remaining two mains.

If  $d_1$  and  $d_2$  are the two deflections so obtained, then the

$$\text{Power factor of the circuit} = \frac{1}{\sqrt{1 + 3 \left( \frac{d_1 - d_2}{d_1 + d_2} \right)^2}}$$

**Correcting Factor for Wattmeters.**—Considering the most common form, namely the electro-dynamometer type, used in practice, it is well known that the current through the moving coil should be exactly in phase with the P.D. at its terminals for the instrument to read *true watts correctly*. It is therefore both interesting and important to know the magnitude of the error introduced into the reading of the wattmeter and the *correcting factor* to be applied to obtain true watts when the current and pressure in the fine wire coil are not in phase due to the coil possessing inductance, which it must necessarily have to some small extent. The following considerations are quite general, and assume that the current and voltage are sine functions—

- Let  $C$  = the maximum current in the fixed coil,
- $I$  = the current (at time  $t$ ) in the fixed coil,
- $E \sin \omega t$  = potential difference between the mains (at time  $t$ ),
- $\phi$  = angle of lag of the current in the mains,
- $i$  = the current (at time  $t$ ) in the moving coil of self-induction  $L$  and total ohmic resistance  $R$ ,
- including any resistance in series with it.

$$\omega = 2\pi \times \text{frequency of the supply.}$$

Then the relations given in Fig. 157<sup>1</sup> can be shown to hold good.

The relations apply to all types of wattmeters if  $\phi$ ,  $L$  and  $\omega$ , the only quantities which vary with the nature of the load and type of wattmeter, are known.

When  $\phi = 90^\circ$  the multiplying factor becomes zero, and the reading of the wattmeter is zero, since there is no force between the coils carrying currents which differ in phase by  $90^\circ$ . The curves (Fig. 157) can be used as follows—Suppose we know that  $L = 0.02$  henry,  $R = 628$  ohms, frequency =  $50 \sim$  per sec., and the power factor = 0.5. Then  $\frac{fL\omega}{R} = 0.01$ .

Hence curve  $C$  is to be used. Now the horizontal line through 0.5 on the power factor scale cuts the power factor curve  $\cos. \phi$  at a point, the vertical line through which passes through  $\phi = 60^\circ$  and cuts curve  $C$  at 0.98, which is the correcting factor of the wattmeter.

### Fundamental Considerations Relating to Alternating Current Static Transformers.

**General Remarks.**—Before considering actual methods of testing *static transformers*, the importance of which, in alternating current systems of distribution of electrical energy, arises from the ease with which a small current at high pressure can be converted to a large current at low pressure or vice versa by such an appliance and with very little loss, some introductory remarks are considered desirable.

There are a great many different forms and ways of building the kind of transformer in question, but they all come under one or other of two main heads, namely—

(a) Those with *closed* magnetic circuits in which the magnetic induction or lines of force are contained solely, or nearly so, in iron.

(b) Those with *open* magnetic circuits in which the lines of force run partly in the iron core of the transformer, and partly in the air through which they complete their path. This type,

<sup>1</sup> Taken, together with Figs. 104 and 146-155 from a paper on "The Measurement of power in alternating current circuits," by P. Hamilton, *Proc. Inst. C.E.*, vol. clix, 1902-1903, by kind permission of the Author and Inst. C.E.

however, has now become practically obsolete. In either case (a and b) the iron core is surrounded by or wound with two distinct and separate coils of insulated copper wire termed the *primary* and *secondary*. In all cases the former is the coil connected to the source of supply, while the latter has induced in it an E.M.F. which supplies current to some separate circuit, usually at quite a different E.M.F. to that acting on the primary.

The primary may be either the high tension (pressure) coil or the low, according as to whether the transformer is used as a step-down or step-up appliance respectively. Hence to avoid confusion, the primary will always be that coil which is connected to the source of supply, whether this be high or low tension.

It may now be well to consider certain phrases and quantities met with in static transformers, and which appear in testing work on them. Transformers with "closed" magnetic circuits only need be considered, the "open" magnetic circuit type not having been made for many years. The induced secondary voltage is evaluated as follows—

Let  $N$  = total magnetic flux threading the secondary winding of  $T_s$  turns,

$f$  = periodicity of the primary supply-current, and hence of this flux,

$E_p$  and  $E_s$  = maximum values of E.M.F.s at the terminals of primary and secondary.

Now since in one period of the current wave, the current and hence the flux varies from 0—max., max.—0, then reverses and again varies from 0—max. and then max.—0, the average rate of change in the flux =  $4N$  lines per cycle or period, and the average change =  $4Nf$  lines per sec. Therefore the average E.M.F. induced per turn =  $\frac{4Nf}{10^8}$ , and therefore the average E.M.F.

induced in the secondary winding of  $T_s$  turns =  $E_s = \frac{4NfT_s}{10^8}$

volts. Since the virtual E.M.F. = average E.M.F.  $\times$  form factor of the voltage wave, the virtual or R.M.S. E.M.F.

$E_s = \frac{4 \times 1.11NfT_s}{10^8} = \frac{4.44NfT_s}{10^8}$  volts, where 1.11 is the value

of the form factor of a sinusoidal wave. There will also be an



induced E.M.F. due to self-induction in the primary winding of  $T_p$  turns, and since the same flux threads this also, this back E.M.F. of self-induction must =  $\frac{4.44N/T_p}{10^8}$  volts. On open secondary circuit the primary supply pressure only exceeds this back E.M.F. by a very small amount, namely, that sufficient to force the energy current through the resistance of the primary winding and provide the necessary magnetizing current for producing the flux in the core. We therefore have the following important relation, namely—

$$\frac{E_p}{E_s} = \frac{4.44N/T_p}{4.44N/T_s} \times \frac{10^8}{10^8} = T_p/T_s$$

very approximately, which is called the *voltage ratio of conversion* or *ratio of transformation*.

If  $A_p$  and  $A_s$  are the currents flowing in the primary and secondary having resistance  $R_p$  and  $R_s$ , then the ohmic drop of voltage in each is  $A_p R_p$  and  $A_s R_s$  respectively, and the core flux is produced by an effective voltage  $\overline{E_p - A_p R_p}$ , where the bar over the expression indicates that it is a vectorial—and not an algebraical—difference, the primary supply E.M.F.,  $E_p$ , and energy voltage,  $A_p R_p$ , not being in phase as indicated in Fig. 158.

The no-load secondary induced voltage will therefore

$$= (\overline{E_p - A_p R_p}) \frac{T_s}{T_p} \text{ volts,}$$

and the secondary voltage on load

$$= (\overline{E_p - A_p R_p}) \frac{T_s}{T_p} + A_s R_s \text{ volts.}$$

When the secondary circuit is *open*, the total loss occurring in the transformer is called the *open-circuit loss*, and the current flowing in the primary is called the *no load primary current*.

The open-circuit loss is made up of the copper loss due to the no-load current flowing in the primary winding, and which is usually very small compared with the remaining loss due to eddy currents and magnetic hysteresis which are termed the iron core losses.



FIG. 158.

The no-load primary current, such as would be indicated by an ammeter, consists of two components in quadrature, namely, (a) the true magnetizing component, which being an idle or wattless current lags  $90^\circ$  behind the supply voltage, and (b) the energy or load component in phase with the supply voltage, and overcoming the above open-circuit losses due to eddy currents, hysteresis, and copper loss.

These three currents can therefore be represented by a right-angled triangle such as Fig. 158, in which  $BD$  would be the no-load current,  $BC$  the energy component, and  $CD$  the magnetizing component. Thus, since  $BD = \sqrt{BC^2 + CD^2}$ , we see that the no-load current  $= \sqrt{(\text{energy current})^2 + (\text{magnetizing current})^2} = \sqrt{I_e^2 + I_m^2}$ , and this no-load current would be in quadrature with the supply volts, except for the energy current, which makes the phase difference slightly less than  $90^\circ$ .

The magnetization or core flux, being directly proportional to the supply voltage at constant frequency, is constant at all secondary loads with a constant voltage supply, and hence *the iron losses are constant at all loads*. Further, since we have seen

that  $\frac{E_p}{N_p} = \frac{T_p}{I_p}$ , it follows that  $\frac{A_s}{A_p} = \frac{T_p}{T_s} = \frac{E_p}{E_s}$ , i.e. the primary and secondary currents are inversely  $\propto$  to the voltages.

The measurements of current, voltage, and power in tests connected, not only with transformers, but also with alternating circuits generally, should be made with instruments possessing practically no self-induction and little or no iron. The best results will be obtained when employing electrostatic, hot-wire, and dynamometer instruments, for such measure the  $\sqrt{\text{mean sq.}}$  values of pressure and current and are independent of the variations of frequency. If a circuit supplied with alternating current is *non-inductive*, as for example a bank of electric incandescent lamps run off the secondary of a transformer, then the  $\sqrt{\text{mean sq.}}$  values of the amperes  $\times$  that of the volts = the *true or mean power* in Watts taken up by that circuit or bank of lamps.

If, however, the circuit is inductive this product (amps.  $\times$  volts) gives what is called the *apparent power* in Watts absorbed, which is in all cases greater than the *true power*. This would be the case if we tried to measure the power given to the primary

of a transformer, which is always very inductive. Recourse must in such cases be had to the so-called *non-inductive Wattmeter*, the fine wire coil of which must have as few a number of fine wire turns as will give the requisite sensibility. Such an instrument will measure the *actual* or *true mean* power given to any circuit, however inductive it is, and no difficulty presents itself in the use of the Wattmeter on a low tension circuit. If, however, the power absorbed in a high tension circuit is required, then a special arrangement of Wattmeter is needed (see p. 42). It is much better, however, to have all measuring instruments on the low tension circuit, and this can be accomplished by employing one of the double conversion methods given in the following pages, a course almost always possible in works and central stations in which two *similar* transformers as regards size and output can generally be obtained.

Another method of measuring the power given to or developed by a transformer is the 3-voltmeter one, and in the case of the primary circuit, a non-inductive resistance of such a *known* value is placed in series with this coil, that the P.D. across its terminals = that across the primary coil, or preferably as nearly so as possible, as this gives maximum accuracy. The method consequently has the somewhat serious disadvantage that the E.M.F. of the supply has to be double that required for the primary alone, which would in the majority of cases preclude its use. Then again a small error in observation may cause a large error in the results.

### (136) The Effect on the No-Load Voltage Ratio, Current, and Watts of a Transformer, of Change of Primary Supply Voltage and Frequency. (Magnetization Curve or Open Circuit Characteristic.)

**Introduction.**—The present investigation is a very important one, in that, amongst other results, it gives the relation between primary terminal voltage ( $\propto$  to core flux at constant frequency) and magnetizing current, and which is termed the "open-circuit characteristic" or "magnetization curve" of the transformer.

The voltage used for the relation should, strictly speaking, be that of the back E.M.F. of self-induction, and therefore the vectorial difference  $V_p - IR_p$ ; but as both  $A$  and  $R_p$  are small, their product is negligibly small compared with  $V_p$ , and can be neglected. Even with the special low-loss iron now used in transformer cores, these are seldom worked at magnetic induction densities outside the limits, 3500 to 7500 lines per sq. cm., in order to minimize the power (due to the iron-loss or energy-current component) absorbed in magnetization, which is con-

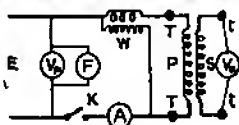


FIG. 159.

verted into heat in the core. For this reason the "knee" of the curve, which corresponds to about 15,000 to 17,000 lines per sq. cm., and is all-important in the design of D.C. apparatus, is never reached in the magnetization curve of a transformer.

Further, since the core loss is obtained in this test and is well known to be practically constant at all loads, it follows that, knowing the resistance of the windings, and hence copper losses ( $I^2R$ ) in  $P$  and  $S$  at any load current, the efficiency can be predetermined at all loads.

The test also shows that both the no-load current and watts decrease as the frequency increases, and hence that higher frequencies reduce the size of core and cost of manufacture for a given output.

**Apparatus.**—Transformer under test, of which  $P$  is the primary and  $S$  the secondary; low-reading wattmeter  $W$ ; voltmeters  $V_p, V_s$ ; switch  $K$ ; frequency meter  $F$ ; low-reading ammeter  $A$ ; source of supply  $E$ , preferably a motor-driven alternator, the speed and excitation of which is variable over a wide range.

**Observations.**—*With Variable Voltage Supply at Constant Frequency.*

(1) Connect up as in Fig. 159, levelling and adjusting such instruments to zero as need it, the terminals  $t$  of the high



(5) From obs. 2 plot the "open-circuit characteristic" (otherwise known as the "magnetization curve") of the transformer having values of  $V_p$  as ordinates, with magnetizing current  $A_m$  as abscissa.

Also curves having the same scale values of  $V_p$  as ordinates, with (a) total no-load current  $A$ ; (b) energy current component  $A_E$ ; (c) no-load watts  $W$  (practically all iron-core losses); (d) voltage ratio  $V_s/V_p$ , as abscissae, in each case. From obs. 3 plot on another curve-sheet curves having values of frequency  $f$  as ordinates, with  $A$ ,  $A_E$ ,  $A_m$ ,  $W$  and  $V_s/V_p$  respectively, as abscissae.

**Inferences.**—From a study of the table of results and shape of curves state clearly all that can be deduced.

### 4(137) Measurement of Copper Losses in a Transformer (by the Short Circuit Test).

**Introduction.**—The total internal loss  $W$  in any static transformer is made up of the iron loss  $W_i$  due to eddy currents and magnetic hysteresis in the iron core, together with the copper loss  $W_c$  due to the currents  $A_p$  and  $A_s$  in the primary and secondary windings of resistances  $R_p$  and  $R_s$ .

Then  $W_c = A_p^2 R_p + A_s^2 R_s$  and  $W = W_i + W_c$ .

Knowing  $R_p$  and  $R_s$ , the copper loss  $W_c$  can be calculated for any or a series of measured load currents, but the value so found may differ considerably from the actual working or effective value, owing to the eddy current and "skin effect" present with the larger sizes of conductor, when carrying alternating current, causing an apparent increase in the resistances  $R_p$  and  $R_s$ . The present test, comprising the direct measurement of the total copper loss, would therefore appear to be a means of obtaining it under working conditions, and hence more accurately than by calculation.

Another source of error may, however, now creep in, for the wattmeter necessary for measuring the loss must obviously be a low-reading one, and have a current capacity equal to that of full load for the winding chosen as primary, while its pressure coil will be subject to a small fraction of what would probably be its normal pressure (a condition introducing an error in its

indication) unless, of course, the wattmeter is a specially designed one for low pressure. The small applied voltage necessary for keeping the short-circuit current within safe limits, will produce a very small induction, and therefore loss due to magnetization of the core. This last named may be negligibly small, when the wattmeter will indicate the copper loss only. If the iron loss is not so small, the wattmeter will give a reading at the applied voltage of short circuit when the secondary is open-circuited, and this reading must be subtracted from all of its indications on short-circuited secondary. Further, care must be taken that the wattmeter reading does not include any losses in connecting or short-circuiting cable. If it does, the loss in such must be separately calculated from their measured resistance and each current, and deducted from the reading.

If  $T_p$  and  $T_s$  = the number of primary and secondary turns respectively, and  $V_p$  = a small supply voltage applied to the primary in order to send full-load current  $A_p$  through it with secondary short-circuited, then the total resistance "drop"

$$= A_p \left( R_p + R_s \left( \frac{T_p}{T_s} \right)^2 \right) \text{ volts.}$$

From the values of this "drop" and  $V_p$  the *characteristic triangle* of the transformer can be drawn and the *leakage drop* determined.<sup>1</sup>

**Apparatus.**—That for test No. 136, excepting that  $W$  and  $V_p$  must now both be low-reading instruments, while  $V_s$  is replaced by a low-resistance ammeter  $A_s$  for short-circuiting the terminals  $tt$  of the secondary winding  $S$ , the range being large enough to indicate at least full-load current of that winding.

**Observations.**—(1) Connect up as in Fig. 159, with the ammeter  $A_s$  across  $(tt)$  and the pressure circuit of  $W$  across  $TT$ , in order to eliminate errors due to including in the reading of  $W$  any copper loss in the primary connecting cables. Level and adjust to zero any instruments which need it.

(2) With an *efficient short circuit* of  $S$  the primary  $P$  will practically constitute a metallic resistance and require, by Ohm's law, probably only two or three volts or so to be applied to it in order to obtain full-load current through it.

<sup>1</sup> Vide "The Testing of Transformers," by Morris and Ideler (*Journal I.E.E.*, vol. 37, p. 284, 1906).

This low voltage required at the normal frequency of the transformer, and from whatever source obtainable, must be adjusted by a suitable variable resistance, in series with  $P$ , so as to give eight or ten currents through  $P$ , varying by about equal amounts from its full-load value to the lowest readable, the readings of  $V_p$ ,  $W$ ,  $A$  and  $A_s$  being noted at each.

(3) Disconnect the secondary short circuit and note the iron-loss reading,  $w_i$  on  $W_i$  for the same value of  $V_p$  as used in obs. 2 (if any is readable).

(4) Measure the resistance  $r_s$  of the short circuit (namely,  $A_s$  and its two short connecting leads) and tabulate your results as follows—

Transformer: No. = . . . . . Made by . . . . . Type . . . . . Voltage Ratio = . . . .  
 Full load: Output = . . . . . KVA. Amps = . . . . . Volts = . . . . . Frequency = . . . .  
 Resistances Primary ( $R_p$ ) = . . . . . ohms i.e. . . . . °C Secondary ( $R_s$ ) = . . . . . ohms  
 Secondary short-circuit ( $r_s$ ) = . . . . . ohms.

Frequency $F$ .	Voltage $V_p$ .	Primary Amps ( $A$ ).	Secondary short-circuit Amps $A_s$ .	Total Watts $W$ .	Power Factor $\cos \phi = \frac{W}{V_p A}$ .	Angle of Lag $\phi$ .	Ohmic Drop $\frac{W}{A}$ .	Core Wtts (if any) $W_i$ .	$A_s^2 r_s$ .	Actual Copper loss $W_c = W - w_i - A_s^2 r_s$ .

(5) Plot a curve having values of copper loss  $W_c$  as ordinates, with  $A$  as abscissae.

**Note.**—The impedance voltage  $V_p$  is entirely spent in overcoming the equivalent impedance of the windings with short-circuited secondary, being partly spent in overcoming resistance and partly in reactance.

$$\text{The reactance voltage} = \sqrt{V_p^2 - (W/A)^2}.$$



### Deduction of the Regulation of a Transformer for any Load and Power Factor from the "Open" and "Short Circuit" Tests.

From the curves obtained in the preceding open and short-circuit tests, the drop in volts in a transformer on non-inductive or inductive secondary load can be predetermined. To obtain this drop is needed the "open-circuit" volts and the triangle of voltages relating impedance voltage, ohmic drop or resistance voltage, and the reactance voltage as obtained from the "short-circuit" test.

The voltage drop in the transformer for any load and power factor can thus be obtained from an exactly similar construction to that given on p. 182 for an alternator, and which will not, therefore, be repeated here.

### (138) Determination of the Regulation of a Static Transformer. (Differential Method.)

**Introduction.**—The meaning of the term "regulation," as applied to a transformer, was explained and defined in test No. 139, p. 412, and its measurement in a single transformer there given. When, however, two similar transformers  $T_1T_2$  are available, the present method of measurement is both simple, convenient, and *direct reading*, whereas that of test No. 139 necessitates taking the difference between two voltages, and is less accurate. It is applicable to any pair of high-tension or low-tension transformers, but the secondary circuit should preferably be the L.T. side, on account of the greater safety in handling instruments at low tension.

**Apparatus.**—Source of A.C. supply  $E$ , whether low or high tension; two transformers  $T_1T_2$ , similar in all respects; voltmeter  $V_s$ ; switches  $S_P S_R$ ; load resistance  $R$ ; ammeter  $A_s$ ; and (if available—for interest, but not as a necessity) two ammeters  $A_{P1}$  and  $A_{P2}$ .

**Observations.**—(1) Connect up as in Fig. 160, levelling and adjusting to zero such instruments as need it.

(2) First connect for  $V_s$  a voltmeter capable of reading (or glow lamps capable of absorbing) the sum of the normal voltages  $N_1 S_2$ . Then with  $S_x$  and  $S_y$  open, and  $E$  giving the normal voltage and frequency of  $T_1$  or  $T_2$ , close  $S_x$ . If  $V_s$  shows a fairly large voltage,  $S_1$  and  $S_2$  are in *helping* series, and the connections of one of them must be interchanged to bring their voltages into *opposing* series, when  $V_s$  will show very little.

(3) Now replace  $V_s$  by a *low-reading voltmeter*, and, with  $S_y$  closed ( $S_x$  still being open), note the readings of  $A_{T1}$ ,  $A_{T2}$  and  $V_s$  (if any). If  $T_1 T_2$  are either exactly *similar*, or *unloaded*, or both,  $V_s$  should now read 0.

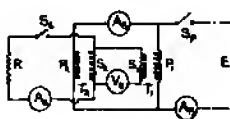


FIG. 160.

(4) With the supply voltage constant, and  $R$  *non-inductive* and full in, close  $S_d$ , taking the readings of all the instruments for each of a series of six or eight load currents  $I_s$ , rising by about equal increments from 0 to the full-load current of  $T_1$  or  $T_2$ .

**Note.**— $V_s$  gives the difference of the voltages between the terminals of the loaded ( $T_2$ ) and unloaded ( $T_1$ ) transformer, which is the required "drop."

The secondary output of transformers is usually expressed in kilo-volt-amperes (K.V.A.), irrespective of the power factor of the secondary circuit, and not in true K.W. at unity or some lower P.F. The values of  $V_s$  may, however, be obtained if desired on inductive loads by repeating obs. 4 with a variable choker ( $C$ ) (not shown), connected in series with the non-inductive resistance  $R$  (preferably a bank of lamps) and a voltmeter with key to measure the volts  $V_s$  across  $R$  and  $V_c$  across the choker at the same current, when the power factor of the circuit will be

$$\cos \theta = \frac{R}{\text{impedance}} = \frac{V_s}{V_c}.$$

Tabulate your results as shown—

Currents for reference.		Secondary Load Current $I_s$	Voltage Drop $V_s$
$I_{P_1}$	$I_{P_2}$		

(5) Plot curves having values of  $V_s$  as ordinates, with values of  $I_s$  as abscissae.

### (139) Determination of the Efficiency and Regulation of Transformers. (Single Conversion Method.)

**Introduction.**—This method is one of the simplest, though not the most accurate, and entails using only the one transformer to be tested. In all cases by the primary of the transformer is meant that winding connected to the supply mains whether these are at high or low tension.

The efficiency of any transformer, supplied at constant voltage and frequency, is the ratio of the secondary output to the primary input, or  $W_2/W_1$ .

The regulation of a transformer is the amount by which the secondary terminal voltage at any secondary load differs from that on open secondary circuit, i.e. it is the "drop" in voltage under load, and is due to both the resistance and reactance of the winding.

The regulation curve therefore relates secondary terminal voltage as ordinates and secondary load current as abscissae. The ordinate intercept between this curve and a horizontal straight line through the "open circuit" voltage point at any secondary load gives the "drop" of voltage at that load.

**Caution.**—In the case of transformers which have to be run off a high tension alternator and are tested by this method, the one operating the high tension instruments must not only wear a pair of carefully selected and good india-rubber gloves, but must also stand on an india-rubber mat, and to guard against the possibility of accidents even in the case of manipulating the low tension instruments, the one operating these must either wear the pair of india-rubber gloves provided or stand on an india-

rubber mat. Before switching on, the "danger boards" provided must be placed close to the high tension wires.

**Note.**—Great care must be taken that the india-rubber gloves are not scratched, cut, or pierced in any way, as this would tend to render them useless for the purposes of insulation.

**Apparatus.**—Alternating current ammeters  $A_1, A_2$  (Fig. 251), and voltmeters  $V_1, V_2$ ; non-inductive Wattmeters  $W_1, W_2$  (with their separate anti-inductive resistances  $r_1, r_2$ , if any); load absorbing resistance  $R$ , preferably non-inductive (p. 598); switches  $S_1, S_2$ ; source of alternating current supply and transformer  $T$  to be tested.

**Note.**— $V_1$  and  $V_2$  should be either hot-wire or electrostatic instruments, of which  $V_2$  may preferably be of the latter type. If  $R$  is strictly non-inductive, then  $W_2$  could be dispensed with; it may, however, as well be used if available.

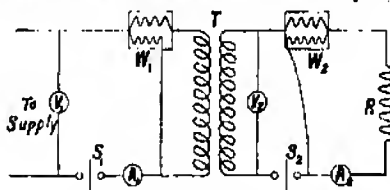


FIG. 161.

**Tests.**—(1) Measure the ohmic resistances  $R_1$  of primary and  $R_2$  of secondary coils in a suitable manner.

(2) Connect up the apparatus as indicated in Fig. 161, carefully levelling such instruments as need it, and seeing that their pointers are at 0. Adjust the voltage and frequency (if possible) of the supply to the normal value required for the transformer.

(3) With  $S_2$  open, close  $S_1$  and note the readings of  $A_1, V_1$  and  $W_1$  simultaneously. The "open circuit losses" occurring in the transformer will thus be obtained.

(4) Make  $R$  large, and close  $S_2$  as well as  $S_1$ . Then note simultaneously the readings of all the instruments for about ten different secondary currents from 0 to full load or to 15% over full load, rising by about  $\frac{1}{4}$  increments.

In all cases the frequency and primary voltage must be kept constant.

(5) Repeat 4 with a higher and lower frequency than the normal.

(6) Repeat 4 and 5 on an inductive load of constant power factor, or otherwise obtain the readings, as detailed on p. 182, necessary for plotting the regulation curves between secondary volts and current, each at different but constant power factors.

(7) Find, experimentally, the copper losses in primary and secondary by passing direct currents of various strengths, between 0 and full load, through the coils, and noting the losses by means of a Wattmeter.

NAME . . . . . DATE . . . . .  
Transformer: No. . . . . Made by . . . . . Transformation Ratio . . . . .  
Normal output = . . . . . Kilo-watts Frequency . . . . . per Sec. Type . . . . .  
Primary Resistance  $R_1$  = . . . . . ohms at . . . . . °C. Secondary Resistance  $R_2$  = . . . . . ohms at . . . . . °C.

Primary.				Secondary.				Voltage Ratio $V_1/V_2$	Regulation $(V_1 - V_2) \times 100 / V_2$	Total Loss in Transformer $W_1 + W_2$	Power Factor $W_1 / (V_1 I_1)$	Copper Losses in Watts.		Total L. Iron Loss in Watts $W_1 + W_2 + W_3$	Efficiency % $100 \frac{W_2}{W_1}$
Volts $V_1$	Amperes $I_1$	Watts $W_1$	Power Factor $\cos \phi_1$	Volts $V_2$	Amperes $I_2$	Watts $W_2$	Power Factor $\cos \phi_2$					Primary $I_1^2 R_1$	Secondary $I_2^2 R_2$		
Apparent $V_1 I_1$	True $W_1$			Apparent $V_2 I_2$	True $W_2$										

Frequency used = . . . . . per sec. Total Secondary amp = . . . . . Volts.

(8) Plot the following curves having values of—(a) Total copper losses; (b) total iron losses; (c) secondary voltage; (d) primary power factor; (e) efficiency; (f) voltage ratio, respectively as ordinates and secondary load currents as abscissae in each case.

**Inferences.**—State concisely all the inferences which you can draw from the results of your experiments.

#### (140) Determination of the Efficiency of Transformers. (Double Conversion Method.)

**Introduction.**—This method can be used when two *similar* transformers are at hand, and particularly when only low tension measuring instruments are available.

**Caution.**—To guard against the possibility of accidents, even in the case of manipulating the low tension instruments, the pair

of india-rubber gloves provided must be worn by the one manipulating the tertiary circuit instruments, and the india-rubber mat must be used by the one reading those on the primary circuit. *On no account must any part of the secondary (high tension) circuit be touched while "alive,"* and before switching on the primary current, the "danger boards" provided must be placed close to the high tension leads.

**Note.**—Great care must be taken that the india-rubber gloves are *not scratched, cut, or pierced* in any way, as this would tend to render them useless for the purposes of insulation.

**Apparatus.**—Alternating current ammeters  $A_1, A_2$  (Fig. 254), and voltmeters  $V_1, V_2, V_3$ , of which  $V_3$  is not absolutely essential to the

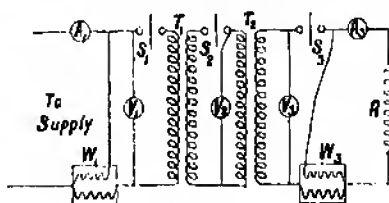


FIG. 162.

test; non-inductive Wattmeters  $W_1$  and  $W_2$  (with their separate anti-inductive resistances  $r_1, r_2$ , if any); switches  $S_1, S_2, S_3, S_4$ ; load absorbing resistance  $R$ , preferably non-inductive (p. 598); source of alternating current supply and the two transformers  $T_1, T_2$  to be tested.

**Note.**—Both  $V_2$  and the high tension voltmeter  $V_3$  should, if possible, be of the electrostatic type. If  $R$  is strictly non-inductive, then  $W_2$  can be dispensed with; it may, however, as well be used if available.

**Tests.**—(1) Measure the ohmic resistance of each of the coils of the transformers  $T_1$  and  $T_2$  in a suitable manner.

(2) Connect up the above apparatus as indicated, carefully levelling such instruments as need it, and seeing that their pointers are at zero. Adjust the voltage and frequency (if possible) of the supply to the normal value required for the transformers.



### (141) Efficiency of High Tension Transformers. (Sumpner's Differential Method.)

**Introduction.**—A neat and convenient method of measuring the efficiency of high tension transformers, and which is susceptible of greater accuracy than most methods, is that due to Dr. W. E. Sumpner, and detailed as follows:—A small auxiliary transformer (*C*), the output of which need not be greater than the waste of power occurring in the two larger transformers *A* and *B*, to be tested, at full load, is required for the purpose of furnishing a small extra voltage (say 5 to 12 volts) necessary for driving the full load or any other currents through *A* and *B*. Its efficiency, goodness, or badness is a matter of indifference, and all we need in connection with it, is the output (*w*) of its secondary in Watts as measured by the Wattmeter (*W*<sub>1</sub>).

The particulars as regards this output can be deduced as follows:—Suppose that two 2250 Watt transformers have to be tested each converting from 100 to 2000 volts or *vice versa*. Then their probable efficiency would be about 94% (say), and hence each would absorb  $22.5 \times 6 = 135$  Watts at full load. Consequently the output of the auxiliary transformer *C* need not exceed  $2 \times 135$  or 270 Watts.

Hence if used on low-pressure 100 volt mains the primary should take about 2.7 amps. at 100 volts, and the secondary give out 22.5 amps. at 2000 volts. In the ordinary test of efficiency of high tension transformers, in which two similar ones are used—one as a step-up from the low-pressure primary mains, and the other as a step-down to the tertiary mains, the efficiency is deduced from measurements of primary input and tertiary output which are of nearly equal magnitude. Consequently the percentage error in measuring these two quantities re-appears as the same percentage error in the efficiency so obtained.

The present method, which is much to be preferred of the two, consists in *actually measuring the losses (*w*)* occurring in the two transformers *directly*, and comparing these with the input to obtain the efficiency.

The method is economical in cost of energy used, especially when testing large transformers; with the methods used in tests



139 and 140 it would be a serious consideration, while the supply of full-load current would make a serious demand on a public supply, or necessitate a large testing alternator. The present method is accurate because the total loss ( $w$ ) in the two transformers is obtained by *adding* together two quantities, and not by subtracting them, and is most convenient for finding the temperature rise after a run of a prescribed number of hours on full load.

The principle of the present method is strikingly analogous to Dr. Hopkinson's combined efficiency test of a pair of dynamos, the distinguishing feature of which is to couple two similar machines together both mechanically and electrically, one to run as a dynamo and the other as a motor. Energy is supplied to one by which it is transferred to the other, this latter returning it again to the source; the balance of energy supplied actually by the source is therefore equal to the waste which occurs in the double transformation and corresponds with the loss ( $w$ ) above mentioned. This then is what takes place in the present case, for energy is taken from the mains by the "step-up" ( $A$  or  $B$ , whichever is used as such), then transferred to the "step-down" transformer, and finally back to the mains again.

Thus, while both transformers can be loaded to any extent by controlling the current circulating between them, the power taken from the supply is only some 4 to 20 % of the full-load K.W. capacity of either, depending on their efficiency—being only that necessary to make up the total internal losses in the two transformers together. Whether the L.T. or H.T. windings are connected to the supply is merely a matter of convenience depending on which supply is available, but usually the L.T. sides are connected to an L.T. supply for safety in handling the more commonly available low-tension instruments, etc. Calling whichever are connected to the supply the primaries, the *secondaries* must be so connected in series that their *E.M.F.s* *oppose* each other. If the primary E.M.F.s are equal, so also will be the secondary E.M.F.s, and no current will flow in the secondary windings. By making the small auxiliary transformer in series with one of the primaries provide a "+" or "-" boosting E.M.F., the out-of-balance primary E.M.F.s so produced will cause out-of-balance secondary E.M.F.s and a circulating secondary

current, the strength of this current depending on the difference between the E.M.F.s. Should the connections be such that the secondary E.M.F.s are in helping series instead of opposing series, as they should be, a short circuit will result. To avoid this, and to ensure the connections of the secondaries being correct, close  $S$  and  $S_1$ , when  $B$  will induce a voltage in the L.T. winding of  $A$  equal to that of the supply, but opposite in phase if the connections are correct. Hence, if either a voltmeter or lamps, each having a voltage range equalling twice that of the supply, are connected across the open switch  $S_2$  and neither show any voltage, the connections are correct for the two L.T. windings, and therefore also the two H.T. windings are then in opposition. If otherwise, the voltmeter or lamps will show *twice the voltage of the supply*. In this event the connections of one of the H.T. secondaries must be reversed. It should be noted that ( $a$ ) will indicate the load current, while an ammeter ( $a_1$ ) in series with  $S_1$  will give the magnetizing current.

If  $W$  = load in Watts supplied to the primary of the "step-up," and  $w_1, w_2$  = the Watts at this load as measured by  $w_1$  and  $w_2$ , and  $\lambda$  = loss of power in the connecting leads, current meter  $a$  and the current coil of  $W_1$ , then the total loss in the two transformers

$$w = w_1 + w_2 + \lambda.$$

$$\text{Hence the efficiency of double conversion} = 1 - \frac{w}{W}$$

$$\text{and the efficiency of either transformer} = \sqrt{1 - \frac{w}{W}}$$

As the ratio of  $\frac{w}{W}$  is small—not greater than  $\frac{1}{20}$  with a transformer of 95% efficiency, the efficiency of each transformer is given quite accurately enough by the relation

$$\Sigma = 1 - \frac{1}{2} \frac{w}{W} - \frac{1}{8} \frac{w^2}{W^2}.$$

An error of 10% in estimating  $\frac{w}{W}$  only affects the combined efficiency to 1%, and that of either transformers to  $\frac{1}{2}$ % only. Hence can be seen the superiority of the present method over the preceding one. The quantity  $W$  can be obtained with quite

sufficient accuracy by the product of the current  $A$  and the P.D. in volts supplied to the primary of the "step-up."

If ( $A$ ) is the "step-up," then  $W = 100 \times$  current in low tension coil of  $A$ , whereas if  $B$  is the "step-up," the power returned to the mains by  $A$  = the above quantity, and hence the input of the primary of  $B$  is

$$W = 100 \times \text{current of } A + (w_1 + w_2 - \lambda).$$

That transformer will be acting as "step-up" which has the higher P.D. of the two ( $A$  and  $B$ ) on its low tension coil. If, say, 12 volts are supplied by  $C$  to the primary of  $B$ , the P.D. at the terminals of  $B$  will be either 112 or 88 volts according as the 12 volts from the auxiliary and the 100 of the mains are in phase or opposite phase. If  $R$  was very inductive, the above voltages would be out of phase, and  $B$ 's P.D. might be anything between 88 and 112 volts.

**Apparatus.**—The two high-tension transformers  $A$  and  $B$  to be tested of say 2000/100 volts; an auxiliary boosting one  $C$ , the primary of which is in series with a variable non-inductive resistance  $R$  of sufficient range to produce only a few secondary volts; two non-inductive Wattmeters  $W_1$   $W_2$ ; Siemens electro-dynamometer or direct reading alternating current ammeter ( $a$ ); switches  $S_1$   $S_2$   $S_3$  and  $S$ ; voltmeter  $V$  for maintaining the mains at 100 volts; alternator  $D$ , or some other source of alternating current.

**Caution.**—On no account whatever is the high tension circuit of either  $A$  or  $B$  to be touched while "alive." The india-rubber gloves and mat must be used by the operators to ensure immunity from accidental shock, or break-down of the insulation between primary and secondary of  $A$  and  $B$ .

**Observations.**—(1) Connect up as in Fig. 163, and adjust the instruments to zero where necessary. See that all lubricating arrangements are working properly, also that the gloves are in good order and the mat suitably placed.

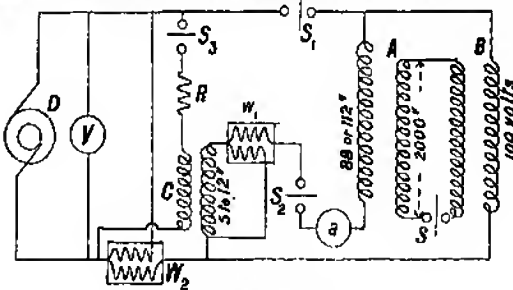
(2) Measure the losses due to the resistance of the leads and instruments employing alternating currents, which can be done without altering any of the connections thus—with  $S$  and  $S_1$  open, short circuit the primaries of  $A$  and  $B$  and close  $S_2$   $S_3$ .

(3) Vary  $R$  so as to obtain about six different currents through ( $a$ ) from 0 to the full load current of  $A$  or  $B$  by causing the secondary voltage of  $C$  to vary suitably. Note the corresponding

readings on  $W_1$  (the power given out by the secondary of  $C_1$ , which therefore at once gives the required losses in Watts in leads and instruments for each particular current passing through them.

(4) Measure the copper losses in the coils of the two transformers  $A$  and  $B$  by opening  $S_1$  and closing  $S_2$  and  $S_3$  and observing the readings of  $W_1$  for some six different currents from 0 to the maximum of  $A$  and  $B$ , as read off on  $a$ .

(5) Measure the iron or core losses in the two transformers *A* and *B* by closing all the switches and observing the reading of  $W_1$ .



Fr. 163

(6) With  $S_2$  and  $S_3$  open, close  $S_1$  and  $S$  and note the readings of  $\alpha_1$ ,  $\alpha_2$  and  $W_x$ . Then  $\alpha_1$  will indicate twice the no-load current of either transformers  $A$  or  $B$ , and  $W_x$  twice the no-load losses in either.

Tabulate your results as follows—

Name . . .

DATE . . .

Transformer used as Step-up: No. ... Type ... Make ...; Resist.  $R_1 = \dots R_2 = \dots$  Ohms.

" " Stop-down: No. .... " : " R<sub>P</sub>=... R<sub>R</sub>=... "

No. ... Output - Value  $\pm$  ... Amps. = ... Constant of Wallmeter  $W_1 = \dots$ 

$\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{x}} \right) = \frac{\partial L}{\partial x}$

Speed in Revs. per min. $R$	Frequency in $\sim$ $f = \frac{R \cdot V}{60}$ $n = \frac{60}{V}$	Current		Total Losses in		Efficiency	
		Reading on $\frac{A}{\mu}$	Angle $\alpha$	Cos. Losses and Instruments $(I^2 R)$ in $\frac{W}{\mu}$	Iron Losses and Instruments $(I^2 R)$ in $\frac{W}{\mu}$	of Combination in % $100 \left( 1 - \frac{W}{P} \right)$	of other transformer $100 \sqrt{1 - \frac{W}{P}}$

(7) Plot the following curves on the same curve sheet having currents ( $i$ ) as abscissæ, and for the ordinates the following—  
 (i) Losses in leads and instruments; (ii) iron core losses; (iii)  $i^2R$  losses in the coils of  $A$  and  $B$ ; (iv) total  $i^2R$  losses in  $A$  and  $B$ . Also with efficiency as ordinates, and load  $W$  in Watts as abscissæ.

(8) Reverse the positions of  $A$  and  $B$ , and repeat the above tests.

**Inferences.**—State very clearly all that you can infer from your experimental results.

### (142) Measurement of the Efficiency of ordinary Single-Phase Transformers by Blakesley's 3-dynamometer Method.

**Introduction.**—This method necessitates the use of two ordinary Siemens electro-dynamometers, in which of course the moving coil is in series with and carries the same current as the fixed coil, whence the angle of torsion is proportional to the  $\sqrt{\text{mean square}}$  value of the alternating current, and in addition the use of a third Siemens electro-dynamometer, arranged so that the moving coil has its own separate terminals, and is not in series with the fixed coil.

If then two alternating currents of equal period, from either the same or different sources, flow through the two independent coils, the periodic time of oscillation of the moving coil being very large compared with that of the current, the angle of torsion is proportional to the *mean* product of the simultaneous instantaneous values of current throughout the period, and is called the "*split dynamometer*" reading.

If  $A_0$  and  $A_0^1$  = maximum values, and  $A$ ,  $A^1$  the mean values of two simple periodic alternating currents, one of which lags behind the other by an angle  $\alpha$ , then the ordinary dynamometer will give  $A = \frac{1}{2}A_0^2$  and  $A^1 = \frac{1}{2}(A_0^1)^2$ . On passing these currents through the split dynamometer its reading  $\phi$  would be  $= \frac{1}{2}A_0A_0^1 \cos \alpha$ , and hence  $\cos \alpha = \frac{\phi}{\sqrt{AA^1}}$ .

The following method is quite general, and does not assume that the current is a simple sine function of the time, but does

assume that there is no magnetic leakage, i.e. that the number of lines cutting the primary and secondary are the same. This is not true in all types of transformers on full load, but is nearly so in closed magnetic circuit types.

Since the split dynamometer gives no reading on open secondary circuit, this method is useless for determining the "open circuit" losses.

**Apparatus.**—Two, ordinary Siemens electro-dynamometers  $A_1, A_2$ , and one split dynamometer ( $A$ ); transformer  $T$  to be tested; non-inductive resistance  $L$  (such as a bank of lamps to take up the secondary load) (p. 598); alternator  $D$ ; switches  $S_1, S_2$ ; voltmeters  $V_1, V_2$ ; non inductive Wattmeter  $W$ , inserted merely for the purposes of comparison.

**Observations.**—(1) Connect up as in Fig. 164, and adjust the instruments to zero where necessary. See that all lubricating cups in use feed slowly and properly, then start  $D$ .

(2)  $S_2$  being open, close  $S_1$ , and adjust the speed and excitation

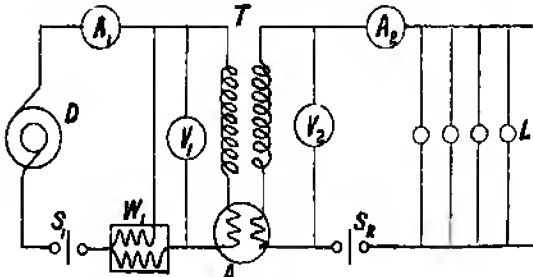


FIG. 164.

so that  $V_1$  reads the normal voltage required for the primary at the normal frequency of the transformer. Note the readings of  $A_1, V_1$  and  $W$ .

(3) Close  $S_2$  and adjust  $L$  so that  $A_2$  reads about  $\frac{1}{10}$  of the maximum secondary current, the voltage  $V_1$  being kept normal by varying the excitation. Now note the readings of  $A, A_1, A_2, V_1, V_2$  and  $W$ .

(4) Repeat 3 for about 10 secondary load currents, rising by



taining a balanced system, the output can quite accurately enough be obtained from the ammeter and voltmeter readings in the manner set forth on pp. 388 *et seq.*

For the present test we will assume that the efficiency of a 3-phase transformer is required. By, say, the single conversion method.

**Apparatus.**—The 3-phase transformer to be tested, of which  $P$  is the primary winding and  $S$  the secondary shown in Fig. 165, with the star or open winding; two non-inductive Wattmeters  $W_1$  and  $W_2$ ; three Parr's direct-reading dynamometer ammeters  $A_1$ ,  $A_2$  and  $A_3$  (p. 572); three voltmeters  $V_1$ ,  $V_2$  and  $V_3$ ; 3-phase variable rheostat  $R$  (non-inductive) capable of operating equally on each line (p. 608); source of 3-phase current  $E$ ; two 3-throw switches  $SSS$  and  $S_1S_1S_1$ .

**Note.**—If the 3-phase rheostat  $R$  is not non-inductive, then two additional Wattmeters will be necessary in the secondary

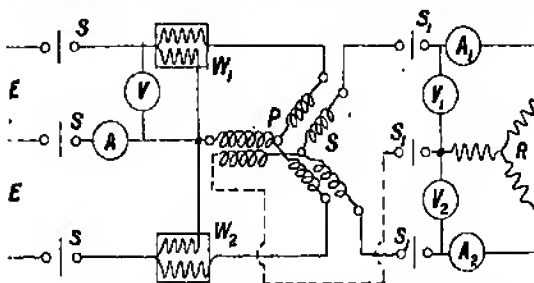


FIG. 165.

circuits connected up in precisely the same way as those shown in the primary circuit, the secondary output being then given by the sum of their readings at any particular load.

**Observations.**—(1) Connect up as in Fig. 165, and adjust all the instruments to zero, levelling such as requires it. See that all lubricating cups in use feed slowly and properly if the source of 3-phase current supply  $E$  is controllable.

(2) With  $S_1S_1S_1$  open, close  $SSS$ , and adjust the speed of the generator so as to give the proper periodicity for the transformer



and then the excitation, so as to have the desired voltage, shown by  $V$  across the primary.

Note the respective Wattmeter readings  $W_1$  and  $W_2$ , and if possible that of  $A$  in addition to  $V$ . Then  $(W_1 + W_2)$  = the no-load primary input = the magnetizing losses.

(3) With  $R$  at its maximum, close  $S_1 S_2$  and note the readings of all the instruments for some ten or twelve secondary load-currents from the smallest to the maximum permissible, rising by about equal increments at a time for constant secondary voltage.

(4) Calculate the secondary loads ( $W_2$ ) from the relation—

$$W_2 = \sqrt{3} A_1 V_1 = \sqrt{3} A_2 V_2 \text{ etc.,}$$

and tabulate as follows—

NAME . . . . . DATE . . . . .  
Transformer tested: No. . . . . Type . . . . . Maker . . . . .  
Normal: Volts . . . . . Amperes . . . . . Periodicity . . . . . Watts . . . . . Constant of }  $W_1$  = . . . .  
Resistances: Each Primary coil  $R_1$  = . . . . ohms, @ . . . . °C. Wattmeter, }  $W_2$  = . . . .  
" : " Secondary coil  $R_2$  = . . . . " @ . . . . °C.

Primary Circuit.				Secondary Circuit.			Total Loss in		
Volts $V$ .	Amperes $A$ .	Apparent Watts $\sqrt{3} A V$ .	True Watts $W_1 + W_2$ .	Volts $E_1$ or $V_2$ .	Amperes $A_1$ or $A_2$ .	Watts $W_2 = \sqrt{3} A_1 V_1$ or $\sqrt{3} A_2 V_2$ .	Transformer $W_T = W_2$ .	Copper Coils $W_C$ .	Iron Core $W_P = W_S - W_C$ .
			Power Factor $\frac{W_1 + W_2}{\sqrt{3} A V}$ .	Angle of Lag $\phi$ .					Efficiency $\eta = 100 \frac{W_2}{W_T} \%$ .

(5) Measure the resistance of the transformer coils by means of either the Wheatstone Bridge or Potential Difference method.

(6) Plot the following curves between—

Efficiencies  $\eta$  as ordinates and secondary loads ( $\sqrt{3} A_1 V_1$ ) as abscissae.

Power Factor as ordinates and secondary loads ( $\sqrt{3} A_1 V_1$ ) as abscissae.

**Inferences.**—State clearly all that can be inferred from your experimental results.

### (144) Efficiency of a Nodon Valve Electrolytic Rectifier.

**Introduction.**—The necessity of obtaining continuous current for certain purposes, such as electrolytic work and the charging of secondary cells, where, frequently, the only available public supply is alternating current, has led to the introduction of rectifiers for rectifying alternating into continuous or unidirectional current.

Of such appliances, there are now several commercially successful forms; that known as the nodon valve consists of as many pairs of cells grouped according to the Leo Gratz method (Fig. 166) as there are phases of current or distributing mains, in order to obtain a single rectified current. Each cell consists of plates formed of an alloy, mainly composed of aluminium, acting as cathode, immersed in a solution of borate or phosphate of ammonium or other salt formed from tartaric, acetic, oxalic or gallic acids. The solution is capable of rapidly altering the condition of the polarizing film formed by an alternating current on the aluminium. The containing cell is made of lead and constitutes the anode. The electrolytic action taking place is as follows—

In one half period of the alternating current, current tends to flow from *aluminium to lead*, but cannot, owing to an insulating film of very high resistance being formed over the aluminium (cathode) plate. In the next half (reversed) period, the current actually is able to flow from *lead to aluminium* owing to the instantaneous de-polarization or reduction of the film on the aluminium plate. The principle on which both semi-waves of the period of an a.c. supply are utilized, is that proposed by Leo Gratz, and shown in Fig. 166, for a single phase alternating—to direct—current transformation. *A* and *I* are the aluminium and lead plates respectively of the four cells *I*, *I*, and *II*, *II*. The continuous arrows represent the direction of current in the valve during one half of a period when the current of the alternating supply flows from *P* to *R*. The dotted arrows show the direction of current in the valve in the next half period when the supply current flows in the reverse direction from

*R* to *P*. Thus for the first half period it is blocked in cells *II*, *II*, and in the second half period it is blocked in cells *I*, *I*. A unidirectional current therefore always flows from *D* to *C* through any load (*r*) whether motor, secondary cells or resistance, etc. To obtain greater constancy or uniformity of d.c. voltage a suitable condenser can be connected across *D* and *C*. A single valve will stand a.c. pressures up to 140 volts between *Q* and *R*, that between *D* and *C* being about 90% of this. For higher a.c. pressures two or more valves may be combined, or an "economy coil" type of transformer connected between valve and a.c. supply. The pressure between *D* and *C* may be varied to any extent by a corresponding variation of that of the supply between *Q* and *R*.

The temperature of the electrolyte must not be allowed to rise much above 50° C., and in large valves, forced air draught around the cells is resorted to in order to keep down the temperature. The valve may be used on any periodicity employed in practice up to 100 ~ per sec. or more. A starting resistance (*S*) must be employed with the valve when this has been out of use for a few hours, in order to reform the insulating pellicule on the aluminium plate. This only takes a few seconds and prevents a sudden heavy rush of current through the valve. The resistance or inductance of *S* is cut out entirely afterwards.

Evaporation of the solution is made up by adding distilled water and the solution need only be renewed at long intervals.

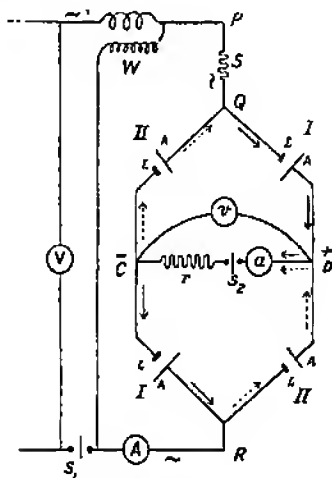
**Apparatus.**—The nodon valve complete; starting resistance (*S*); alternating current ammeter (*A*), voltmeter (*V*), wattmeter (*W*); direct current ammeter (*a*), voltmeter (*v*); load or variable resistance (*r*); thermometer; source of a.c. supply; economy coil or transformer if a.c. supply exceeds 140 volts; switches *S*<sub>1</sub>, *S*<sub>2</sub>.

**Observations.**—(1) Connect up as in Fig. 166, and adjust all the instruments to zero, levelling such as require it. *Q* and *R* are the terminals marked **ALT** on the valve, and are to be connected to the a.c. supply; *D* and *C* are the terminals marked + and -. If machinery is being run for supplying the valve, see that all oil cups feed very slowly and properly.

(2) With *S*<sub>1</sub> and *S*<sub>2</sub> open and *B* full in, adjust the a.c. supply so that *V* reads about 140 volts, the periodicity being kept constant at normal value. Now close *S*<sub>1</sub>, and note the readings of all the instruments.

(3) With  $S_2$  still open, gradually cut out  $S$  to short circuit and again note all instrumental readings and the temperature of the electrolyte.

(4) Reinsert  $S$  and with  $(r)$  full in, close  $S_2$  and gradually cut out  $(S)$  to short circuit. Next adjust  $(r)$  so that  $(a)$  reads about  $\frac{1}{10}$ th full output current and note the readings of all the instruments.



### Three Phase (Balanced)

**Fig. 106.**

(5) Re-adjust ( $r$ ) so as to obtain some ten different load currents on ( $\alpha$ ) rising by about equal increments to the maximum for which the value is intended, and note the temperature and readings of all instruments at each.

(6) Repeat (5) for a widely different but constant periodicity (if available) above and below normal at the same voltage if possible.

(7) Repeat (5) for a constant supply voltage, say 50% less than before, at normal periodicity.

(8) Open ( $S_2$ ) and at constant normal periodicity, note the readings of all the instruments for ten different voltages between 0 and 140 volts.

(9) With a convenient constant supply voltage and  $S_2$  open, take readings of all the instruments for ten different periodicities, ranging from the maximum obtainable downwards.

(10) Repeat both (8 and 9) for  $S_2$  closed, constant full load being maintained on ( $a$ ) by varying ( $v$ ), and tabulate all results as follows—

NAME . . . . . DATE . . . . .  
 Neon Valve: No. . . . . No. of coils . . . . .  
 Area of Anode . . . sq. in. Area of Cathode . . . sq. in.  
 Maximum output Amperes = . . .

Value of $S$ .	Temp. of Solution.	Periods per Sec.	Primary.					Secondary.			Voltage Ratio of conversion $\frac{e}{V}$	Efficiency as $\frac{W}{P}$
			Volts ( $V$ )	Amps ( $A$ )	Wattmeter Reading $WP$	True Watts $W$	Ap. correct Watts $AP$	Power Factor $\frac{W}{AP}$	Volts ( $v$ )	Amps ( $a$ )	Watts ( $ac$ )	

**Note.**—If the valve is cooled by forced air draught, the power absorbed in producing the draught must be added to the true watts ( $W$ ), or watts ( $ac$ ), according to whether it is supplied by the primary or secondary circuit respectively.

(11) Plot curves on the same sheet, having values of—power factor; volts ( $v$ ); efficiency; and voltage ratio as ordinates, with secondary load ( $ac$ ) as abscissæ; also between efficiency as ordinates and temperature as abscissæ at constant secondary load.

(12) Plot curves (for Exp. 8 and 10) with voltage as abscissæ and the other quantities as ordinates; also (for Exp. 9 and 10) with periodicity as abscissæ and the other quantities as ordinates.

**Inferences.**—State clearly all the inferences deducible from experimental results.

### (145) Efficiency of a Rotary Rectifier.

**Introduction.**—Rotary rectifiers are employed for the purpose of rectifying single-phase alternating current into unidirectional or continuous current, and comprise a special form of commutator driven at synchronous speed by a suitable single-phase synchronous a.c. motor.

The now well-known Ferranti rotary rectifier comprises, in addition, a constant-current static transformer, which, when supplied with varying a.c. at constant pressure, automatically delivers constant direct current at varying pressure for supplying arc lamps in series. Since the motor is driven in this case from a separate secondary coil on the static transformer, the ratio of the d.c. power output to the a.c. power intake by the primaries of the transformer gives the overall net efficiency which may be over 91% at a full load of 40 H.P. with a power factor of 0.90.

In the Morton and Wright rotary rectifier there is merely the special commutator and synchronous motor, the rectification being from varying current at constant a.c. voltage to varying current at constant voltage on the d.c. side.

**Apparatus.**—The rectifier complete comprising—motor  $M$ , commutator  $B$ , diphaser  $P$  and starting switch  $S$ ; ammeters  $A_m$ ,  $A_A$  and  $A_U$ ; voltmeters  $V$  and  $V_U$ ; switches  $S_1$ ,  $S_m$ ,  $S_A$  and  $S_U$ , and two-way voltmeter key  $K$ ; wattmeter  $W$ ; load absorbing device  $R_o$ ; and non-inductive regulating resistance  $r_m$  (if necessary).

**Observations.**—(1) Connect up as in Fig. 167. The terminals marked (m) Fig. 167, are for the motor circuit, and those marked  $DC$  and  $AC$  are the terminals for the direct and alternating currents sides of the rectifying commutator  $B$ . Adjust all the instruments to zero, levelling such as requires it, and see that the bearings of the rectifier, and those of any other machine in use, are properly lubricated before starting. See also that the two brushes, which rub on the central-sectioned part of the rectifying commutator, are adjusted to touch on the thin strips simultaneously.

(2) With the switch ( $S$ ) on the stud marked *Start*, close  $S_1$  and  $S_m$  only, and move the brush rocker on the motor itself, until the machine emits a constant hum and runs quite sparklessly, when it will then be in synchronism with the supply. Now switch  $S$  to the right-hand contact and if necessary re-adjust the position of the rocker to obtain sparkless commutation.

(3) With  $K$  on  $V_m$ , note the readings of  $W$ ,  $A_m$  and  $V$ .

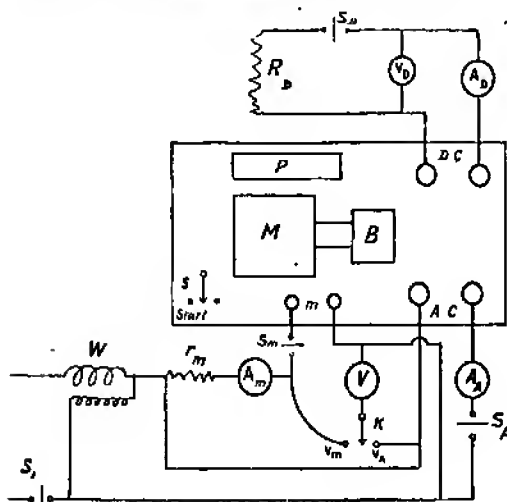


FIG. 167.

(4) With  $R_d$  full in and  $S_2$  open close  $S_A$  and again note  $W$ ,  $A_m$ ,  $V$ ,  $A_A$  and  $V_d$ ,  $K$  now being on stud  $V_A$  and  $V_m$  in quick succession.

(5) Close  $S_d$  and note the readings of all the instruments for about ten different currents on  $A_d$ , from 0 to full load, by varying  $R_d$ ; adjusting the brush rocker of the rectifying commutator to get sparkless rectification at all loads.

Tabulate all your results as follows—





into that of another. To this class belong the various forms of multiphase rotatory converters. Those converting from multiphase alternating currents to continuous currents or *vice versa*, are usually multipolar machines, having any number of pairs of poles up to about 16 or more, with a periodicity ranging from 20 to something like 60  $\sim$  per sec. Owing, however, to the conditions imposed by the relations between voltage, speed and size, they usually operate best at the lower periodicities.

The rotatory converter to be tested consists of an ordinary direct-current machine, with the usual armature winding and its commutator at one end and three slip rings at the other, connected to three points on the armature winding—0,  $\frac{2}{3}$  and  $\frac{4}{3}$  of the polar pitch apart, i.e. in a two-pole machine at 120° apart. The machine when driven as a motor by direct currents taken in at the ordinary commutator end develops a 3-phase alternating current at the slip rings. It is this type of converter which is beginning to be used now on a large scale, only with more than one pair of poles, in long distance transmission of power, as follows—Polyphase alternating currents being transmitted at high pressure from the distant generating station, are reduced to, say, 100 to 300 volts by static transformers at the near end and then converted by the rotatory converter into direct currents, which may be employed for tramway, lighting, electrolytic purposes, or for charging storage cells. In any converting appliance, and therefore in any converter, the *(total energy put in) - (total energy given out) = (total internal losses)*. These are made up of mechanical frictions at journals, brushes, and due to wind or air churning, magnetic hysteresis, eddy currents and copper losses.

Owing to the armature reactions of the dynamo and motor currents practically balancing one another, *no lead* of the brushes in either direction is needed for sparkless running.

A rotary converter is usually run from the A.C. side in practice, but when "inverted," i.e. run from the D.C. side, as in the present instance, the nature of the external circuit will have the same effect on its field as it has on that of an A.C. generator, but with additional effects.

Thus on inductive load or power factor less than unity, a leading current will cause an armature reaction which will strengthen the field and hence reduce the speed, while a lagging

current will cause a reaction that will weaken the field and hence increase the speed, in either case producing a change of frequency.

In fact, the increase of speed may become excessive from either small lagging power factors or short circuit causing excessive weakening of the field, which can only be counteracted by an increase in the natural excitation of the field proportional to the effect causing the increase of speed.

**Apparatus.**—Multiphase converter  $C$  to be tested in the present case assumed to be for 3-phase currents; source of direct-current supply  $E$ ; direct-current ammeters  $A$  and  $a$  and voltmeter  $V$ ; alternating current ammeters  $A_1, A_2, A_3$ , and voltmeters  $V_1, V_2, V_3$ ; non-inductive 3-phase rheostat  $R_1, R_2, R_3$ , and ordinary ones  $R$

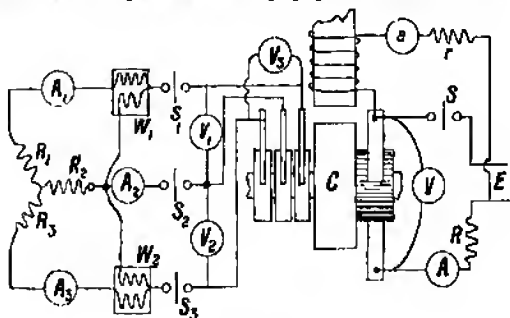


FIG. 168.

(p. 606) and  $r$  (p. 599); triple-pole switch  $S_1, S_2, S_3$  and  $S$ ; non-inductive Wattmeters  $W_1$  and  $W_2$ ; tachometer.

**Note.**—Certain pieces of the above apparatus are not absolutely necessary to the test, but when available may preferably be inserted and used so as to clearly show what is actually taking place. Thus if the three resistances  $R_1, R_2, R_3$  constitute a proper 3-phase rheostat (water or otherwise) (p. 607), which operates equally on each of the mains, then in addition to apparatus as before we need only have—one single 3-phase rheostat  $R_1, R_2, R_3$ ; one ammeter  $A_1$  and voltmeter  $V_1$  instead of the three; one 3-throw switch  $S_1, S_2, S_3$ , to close the three circuits simultaneously, and one Wattmeter.



(5) Repeat 2-4 for a highly inductive circuit  $R_1 R_2 R_3$ .

(6) From observations 2-5 plot the efficiency curve having  $H_2$  as abscissae and  $\Sigma$  as ordinates.

The external or *a-c* characteristic with  $V_1$  as ordinates and  $A_1$  as abscissae.

The current characteristic with  $A$  as ordinates and  $A_1$  as abscissae.

The voltage ratio, input, and speed as ordinates and  $H_2$  as abscissae.

From the current characteristic indicate how the efficiency of the converter could be calculated at any load and also work out the ratio of current transformation.

**Inferences.**—State very clearly all that can be deduced from your experimental results.

**Note.**—If  $n$  = number of armature windings per radian,

$e$  = maximum E.M.F. per turn of winding,

and if we assume the flux in the interpolar space to be sinusoidally distributed, and that the E.M.F. is a sine function of the time, then the voltage ratio of conversion with 3 phase connections

$$= \frac{\sqrt{3}}{2} \frac{e n t}{\pi s} = \frac{1}{2} \sqrt{\frac{t}{s}}$$

and the virtual voltage across any pair of slip collector rings will = 61.23 when that impressed on the direct current side = 100 volts.

In other words, the voltage ratio of conversion *with sine distribution* of flux in the interpolar spaces

$$= 61.23\%$$

As, however, the flux is never so distributed, and, moreover, as the voltage ratio depends to a large extent on the polar arc, pole, shape and position of the brushes, the above ratio is only roughly about what may be expected.

The  $C^2R$  total loss and temperature rise will be less in the machine used as a converter than when used as a dynamo.

**(147) No-Load (open circuit) Characteristic or Magnetization Curve of Continuous-Alternating Current Rotary Converters. (Run from the Continuous Current Side.)**

The No-Load Characteristic or curve of magnetization of a converter from which its magnetic properties and most suitable excitation is seen can be obtained in one of the two following ways—

(1) By driving the rotary at *constant speed* from a direct coupled motor, or by belting, and noting the readings of the voltmeters across the d.c. and a.c. sides respectively for each of some ten values of exciting current obtained from some outside d.c. supply, and differing by about equal amounts from 0 to say 25% above normal excitation and taking a similar descending set of readings.

(2) By connecting up exactly as in Fig. 168 and driving the rotary as a motor from its d.c. side.

With the field current ( $\phi$ ) adjusted to say 20 % above its normal value (if possible) start the rotary up in the usual way to maximum speed obtainable with this excitation, and  $R$  cut out. Note the readings of speed (to insure constancy throughout) and both a.c. and d.c. voltages for this maximum excitation, and for each of about ten smaller values obtained by increasing  $r$  and differing by about equal amounts down to the minimum practicable, the speed being kept at the same constant value by increasing  $R$ , and tabulate as on page 436. Plot the magnetization curve, having exciting currents as abscissæ, and the a.c. and d.c. voltages as ordinates respectively.

Deduce a third curve by joining the points obtained on deducting the armature drop ( $=$  current  $\times$  its resistance) from each of the d.c. voltage ordinates.

Plot also a curve having a.c. volts as ordinates with d.c. volts as abscissæ and deduce the voltage ratio of conversion. Compare this ratio with the theoretical value and explain the reason for any difference.

**(148) Effect of Variation of (1) Excitation  
(2) Speed on the Voltage Ratio of a  
Rotary Converter (Run from the Direct  
Current Side.)**

**Observations.**—(1) With exactly the same connections as in Fig. 168, and with  $S_1, S_2, S_3$  open, note the readings of all the instruments for constant speed throughout, for about eight different values of exciting current ( $a$ ) differing by about equal amounts between the minimum and maximum values possible.

(2) Repeat (1) with  $S_1, S_2, S_3$  closed, and at  $\frac{1}{2}, \frac{1}{3}$  and full load respectively, the load being kept constant by varying  $R_1, R_2, R_3$ .

(3) Repeat 1 and 2 for a similar variation of speed at constant normal excitation and tabulate as on p. 436.

Plot curves for Tests 1 and 2 at each load having exciting currents ( $a$ ) as abscissas, and (1) a.c. volts, (2) d.c. amps, (3) voltage ratio of conversion, as ordinates in each case, and for tests (3) curves having speeds as abscissas with voltage ratio; a.c. volts and d.c. amps. as ordinates.

**Inferences.**—State concisely all that can be deduced from the results of your investigations in the present test.

**(149) Efficiency and Characteristics of Alternating-Continuous Current Rotary Converters. (Run from the Alternating Current Side.)**

**Introduction.**—The investigations to be made in the present case are all the more important and instructive because the usual application of this kind of rotary, commercially, is to convert a.c. to d.c., the machine being supplied with a.c. and running as a synchronous a.c. motor. The speed at which it runs will therefore solely depend on the number of poles in the field, and on the periodicity of the a.c. supply, and if this latter is constant the speed will be also, irrespective of the load developed at the d.c. side, or of the excitation. As the load increases, for constant power factor, a.c. voltage, and frequency, "armature reaction" causes an increasing drop of d.c. voltage, and, farther, a decrease of excitation is necessary to maintain constant power factor, but

an increased variation of d.c. voltage results. On the other hand, a constant excitation increases the intake current, but decreases the variation of d.c. voltage. By varying the excitation to maintain constant d.c. voltage, this latter, and also the efficiency, is increased. In order to minimize the variation of d.c. voltage, and maintain a constant voltage ratio as the load changes, rotaries are usually compound wound, the series coils, just as in the case of an ordinary compound dynamo, producing an increase of excitation proportional to the load, and simultaneously, the necessary change of power factor. A rotary can be over-compounded so as to give an increasing d.c. voltage with load to make up for loss of voltage in transmission, in which case unit power factor is obtained by field regulation at some fraction of full load, thereby giving leading currents at full load. On a light constant load, a given variation in the excitation causes a much greater change in the current intake and power factor than it would do on a heavy constant load. Since the lost armature volts in a rotary run from its a.c. side = (current  $\times$  armature impedance), while when run from its d.c. side this quantity = current  $\times$  armature resistance, and also owing to the power factor not being unity; to the wave-forms of a.c. supply, and of the rotary (run from the d.c. side) being different; and to armature reaction, the voltage ratio of conversion will be different when run from the d.c. and a.c. sides. Further, when the power factor of the circuit is low and the current comparatively large and lagging, the supply and lost armature volts will be more nearly opposite in phase, and hence a larger armature drop results at the small excitations. A rotary has unit power factor at a particular excitation, also too low an excitation causes the current to lag, while too high an excitation causes it to lead as shown by the  $V$  curves between excitation and power factor obtained in the above investigation. Constant d.c. voltage at all loads can be maintained by adjusting the excitation to give unit power factor at full load.

**Apparatus.**—Precisely that prescribed for Test 146, except that the a.c. supply is substituted for, and takes the place of,  $R_1$ ,  $R_2$ ,  $R_3$ , and that some form of synchronizer is needed. If the phases are equally balanced, or if all the instruments on the a.c. side are unavailable, then any two ammeters such as  $A_1$  and  $A_2$ , and any two voltmeters such as  $V_1$ ,  $V_2$ , may be omitted. Also one

of the two wattmeters shown might be omitted, means being provided by a two-way key for connecting one end of the fine wire coil of the wattmeter used to the remaining two supply mains in quick succession. It will be noticed that a three phase rotary is assumed for the test, but the same considerations and investigations would apply to single- and two-phase rotaries.

**Connections.**—To be as shown in Fig. 168, unless modified by a reduction in the number of a.c. instruments as mentioned above. The simplest and most convenient form of synchronizer to employ consists of two ordinary glow lamps supported in two ordinary bayonet holders connected in series and carried on a base board with two terminals. The sum of the voltages marked on the lamp bulbs *must not be less than* the sum of the supply and converter a.c. voltages. The two terminals of this "lamp synchronizer" may be connected so as to short circuit  $S_1$ , say a piece of thin wire short circuiting, say,  $S_4$ .

**The Process of Synchronizing** the rotary with the a.c. supply is usually most conveniently accomplished as follows—

(a) Adjust all instruments which need it, and with  $S_1$ ,  $S_2$ ,  $S_3$  open, start the rotary up as a d.c. motor from a d.c. supply  $E$ , by closing  $S_4$  and operating the starter (not shown), with which the machine is provided, in the usual way.

**N.B.**—If there is no starter, the adjustable load resistance  $R$  may be used for starting up.

(b) Adjust  $R$  so as to obtain the same voltage on  $V_2$  as that of the main a.c. supply, and then adjust  $r$  to give such a speed that the lamps go out. The a.c. supply and a.c. voltage of the rotary are now equal to, and opposing, one another, and of the same frequency, and hence in synchronism. The switch  $S_1S_2S_3$  must now be closed, and  $S_4$  at once opened, when the rotary will continue to run, now as a self-exciting three-phase synchronous a.c. motor.

It may be mentioned that the a.c. voltages of the main supply and of the rotary are in assisting series when the lamps show steady luminosity, while between this and the "quite out" condition they pulsate in brightness due to the current pulses of the two E.M.F.s trying to catch up to one another.

Of course, a separate motor, or driving source, if available, might be used to run the rotary up to synchronous speed instead



of the d.c. supply above named. If the d.c. supply used for starting-up purposes is unsuitable for giving the necessary a.c. voltage on the rotary at the required speed, the rotary may be run up to a much higher speed than that of synchronism,  $S$  then being opened, and afterwards  $S_1 S_2 S_3$  closed, at the moment when the speed falls to such a value that the lamps go out.

**Note.**—If an outside d.c. supply is used in synchronizing, then directly the rotary is running synchronously on the a.c. supply and  $S$  is opened, at once disconnect the mains  $K$  from the auxiliary d.c. supply, and connect them together to avoid the possibility of a future mishap by forgetting to do this at the time. Several investigations on the operation of the converter under different conditions can now be undertaken.

### Effect of variation of Direct Current Load on the operation of the Converter at Constant Direct Current Voltage and Excitation, and Alternate Current Frequency.

**Observations.**—(1) Adjust the exciting current ( $a$ ) by means of ( $r$ ) until the intake a.c. is a minimum, then with  $S$  still open, note the readings of all the instruments and the speeds of the rotary and generator (giving the main a.c. supply) respectively for normal frequency.

(2) Close  $S$  and note the readings of all the instruments and the speed, for about eight different d.c. loads rising by about equal amounts between 0 and full load, by varying  $R$ ; keeping the current ( $a$ ), the supply frequency, and the d.c. voltage ( $V$ ) (by varying the excitation of the main generator), constant throughout.

(3) Repeat (1 and 2) above for a lower and also for a higher constant excitation than that previously found in Test 1 above, and tabulate your results as shown in the table.

(4) Plot curves between d.c. output in amps.  $A$  as abscissae, and (a) efficiency  $\%$ , (b) power factor, (c) mean intake a.c. amperes, (d) mean a.c. volts, as ordinates in each case.

**(150) Effect of variation of Direct Current Load on the operation of the Converter at Constant Alternate Current Voltage and Frequency, and Direct Current Excitation.**

**Observations.**—(1) With constant normal a.c. voltage and frequency maintained throughout, repeat (1—4) Test 149 above, plotting for (1d) above the d.c. volts instead of mean a.c. volts as ordinates. The curve between  $V$  and  $I$  is called the d.c. characteristic of the rotary.

**(151) Effect of variation of Excitation on the operation of a Converter at Constant Alternate Current Voltage and Frequency, and Direct Current Load ("V" curves).**

**Observations.**—(1) With  $S$  open, and the converter running at constant normal a.c. voltage and frequency, note the readings of all the instruments, and the speeds of the main generator and rotary for about eight different exciting currents ( $a$ ) between the lowest and highest permissible by altering ( $r$ ).

(2) Close ( $S$ ) and repeat (1) for constant loads of about  $\frac{1}{2}$ ,  $\frac{1}{4}$ ,  $\frac{3}{4}$  and full d.c. load and tabulate as indicated.

(3) Plot curves between d.c. amperes of excitation as abscissae and ( $a$ ) power factor, ( $b$ ) intake alternating current, ( $c$ ) voltage ratio of conversion, ( $d$ ) intake a.c. Watts.

**(152) Variation of Excitation to Maintain Maximum Power Factor for Varying Direct Current Load at Constant Alternate Current Voltage and Frequency.**

**Observations.**—(1) With  $S$  open, and the rotary running at constant normal a.c. voltage and frequency, adjust the excitation ( $a$ ) so as to obtain minimum intake current, and note the readings

of all the instruments and the speeds of main generator and rotary.

(2) Close  $S$  and note the value of the exciting current (a) necessary to give *minimum intake current* at about 8 different d.c. loads between 0 and the maximum (by altering  $R$ ), the a.c. voltage and frequency being the same at each load. Note all the other instrumental readings and tabulate as indicated.

(3) Plot curves between d.c. load in watts as abscissae and (a) d.c. volts, (b) exciting current, (c) a.c. amperes, (d) power factor, (e) voltage ratio of conversion, (f) efficiency.

Name . . . . . Date . . . . .  
 Rotary: No. . . . . Type . . . . . Maker . . . . .  
 d.c. Side: Volts = . . . . . Amps = . . . . . Speed = . . . . .  
 a.c. Side: Volts = . . . . . Amps = . . . . . Wattmeter Constants  $K_1 = \dots$ ;  $K_2 = \dots$   
 Resistances:—Armature  $r_a = \dots$  Shunt  $r_{sh} = \dots$  Series  $r_{se} = \dots$

Speed of		Main Alternating Current Supply.							
Generator.	Rotary.	Frequency.	Currents.			Voltages.			Wattmeters.
			$A_1$	$A_2$	$A_3$	$V_1$	$V_2$	$V_3$	$W_1$ $W_2$

Total Watt Input		Direct Current Output.							
True $K_3 W_1 + K_2 W_2$ Apparent $\sqrt{3} A_1 V_1$	Power Factor $\cos \theta = \frac{W}{\sqrt{3} A_1 V_1}$	Amps in		Volts $V$	Watts $W$	Loss Excitation Watts $W_{ex}$	Natural Efficiency $\frac{W}{W + W_{ex}} = \eta$	Mean Voltage Ratio of Conversion $\frac{V_1 + V_2 + V_3}{V}$	Gross Efficiency $\frac{W}{W + W_{ex}}$
		Shunt $A_s$	Main $A_m$						

**Inferences.**—Very carefully consider and state all the inferences which can be deduced from the results of your investigations.

### (153) Efficiency and Output of a "Booster" or of a "Motor Generator Set."

**Introduction.**—It frequently happens in practice that either electrical power in one form at a certain pressure is required in the same form but at a different pressure, or that electrical power of one nature is required in quite a different nature at the same pressure or otherwise. The electrical appliance by means of which such transformations can be effected is variously termed a

"Motor Generator," "Booster," "Rotatory Converter," "Continuous Current Transformer," etc.

In all these appliances the desired effect is produced by machinery in motion, and only so long as it is in motion. The motor-driven Booster at the present day is essentially a device for transforming direct-current energy from one pressure to another. Speaking in general terms a Booster is a machine for adding a small percentage of E.M.F. to a large generator and is much used in storage battery systems. The Motor Generator and Converter very frequently constitute a device for transforming electrical energy in the form of direct currents into that of the

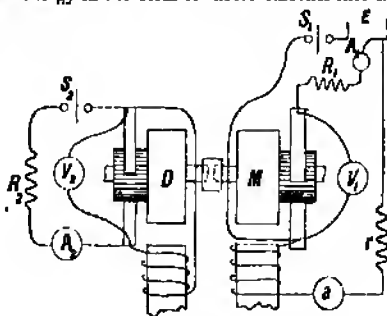


FIG. 109.

form of single and multiphase alternating currents or vice versa. The motor generator frequently takes the form of two separate machines, on the same bed plate, with their shafts in alignment and coupled mechanically. One machine *M* constitutes an electro-motor, fed from an external source of electric supply, the other is a generator *D* which is driven direct by the motor and develops electrical power.

As machines of this nature are used to some considerable extent as "regulators" to "feeder mains," and also with some slight constructional difference as "equalizers" on the various systems of parallel distribution, the determination of their efficiency and output becomes of considerable importance.

**Apparatus.**—Motor generator *MD*; source of electrical energy *E*; ammeters *A*<sub>1</sub>, *A*<sub>2</sub> and *a*; voltmeters *V*<sub>1</sub> and *V*<sub>2</sub>; rheostats *R*<sub>1</sub>, *R*<sub>2</sub> (p. 606) and *r* (p. 599); switches *S*<sub>1</sub> and *S*<sub>2</sub>; tachometer.

**Note.**—Prior to starting, all lubricators must be seen to feed properly.

**Observations.**—(1) Connect up as in Fig. 169, and adjust the pointers of all the instruments to zero. Increase  $R_1$ ,  $R_2$  to their maximum and  $r$  to a minimum. See that  $S_1$ ,  $S_2$  are open and both sets of brushes down.

(2) Close  $S_1$  and adjust  $R_1$  so that the normal speed  $N$  for the particular "set" tested is obtained. Note simultaneously the readings of  $A_1$ ,  $a$ ,  $V_1$ ,  $V_2$  and  $N$ .

(3) Close  $S_2$  and adjust  $R_1$ ,  $R_2$  so that  $A_2$  reads about  $\frac{2}{3}$  full load current in amperes,  $N$  being the same as before. Again read all the instruments.

**N.B.**—It may be found necessary to vary the excitation of  $M$  by means of the resistance  $r$  in order to keep the speed constant throughout any one set of readings.

(4) Repeat 3 for about ten different load currents  $A_2$  up to the maximum, rising by about equal increments at a time.

(5) Repeat 3 and 4 for speeds 20% above and 50% below normal, and tabulate your results as follows—

Name . . . . . DATE . . . . .  
 Maker of Motor Generator . . . Resistance of Shunt Cyl of  $M$  ( $r_s$ ) = . . . ohms.  
 Number of " . . . Type . . . Normal Output = . . . Watts at . . . revs. per min.

Speed $N$ .	Shunt Current $a$ .	Watts used in Shunt $a^2 R_s$ .	Current $A_1$ Amperes.	Volts $V_1$ .	Watts $A_1 V_1$ .	Total Power absorbed by Motor $A_1 V_1 + a^2 R_s$ .	Current $A_2$ Amperes.	Volts $V_2$ .	Net Output of $M$ in Watts $V_2 A_2$ .	Efficiency of Motor Generator $\eta = \frac{V_2 A_2}{A_1 V_1 + a^2 R_s} \times 100 \%$ .

(6) Plot an efficiency curve for each speed having  $W_2$  as abscissae and  $\eta$  as ordinates. Also curves having  $W_1$  as ordinates.

**Inferences.**—State clearly all the inferences which you can draw from the results of your experiment. Could the combined efficiency be increased by any structural alterations in the "set" tested?

#### (154) Determination of the Periodic E.M.F. and Current Curves of an Alternator.

**Introduction.**—It may sometimes be desirable to determine the periodic curve or wave of E.M.F. and current in an alter-

nating current circuit, for the shape of such curves has an important influence on the losses occurring in the iron cores of any appliances in the circuit. In fact, the more peaked the E.M.F. curve, or the more nearly it approximates to a sine or even a triangular curve, the less will be the losses occurring in such appliances and the greater will be what is called the "*form factor*."

Two cases may arise in which it is desired to obtain the periodic curves, namely (1) when the alternator supplying the circuit is at a long distance away, and consequently inaccessible in a sense, (2) when the test can be applied close to the alternator, if necessary. In either case some convenient form of rotating contact maker must be used to close the circuit of a suitable measuring arrangement for an instant once every revolution, at any definite point in the period of alternation, corresponding to the position of the brush or contact arm. Hence by moving this contact arm into various angular positions, the periodic curve of instantaneous values of varying E.M.F. and current at different instants can be obtained throughout the whole period or wave. Such a contact maker is illustrated and described in the Appendix, p. 619, and in case 1 above it is fitted to and driven by a synchronous alternating current electromotor run off the supply of which the E.M.F. or current curve is desired. Such a motor always runs at a speed bearing a definite and fixed ratio to the periodicity of the supply current. In case 2, the one we shall here consider, the contact maker is fixed to, and is driven by, the rotating portion of the alternator itself.

Knowing then the periodic curves of E.M.F. and current in a circuit together with their *phase difference*, at once seen from the relative positions of the two curves, the true instantaneous power developed in that alternating current circuit can at once be deduced.

The following method of obtaining such curves consists in charging a condenser to a certain E.M.F. by periodically connecting it, by means of the contact breaker, to the alternating circuit to be tested, and measuring this E.M.F. by an electrostatic voltmeter. This will therefore be the instantaneous value of the potential at the point of the period of alternation corresponding to the position of contact of the brush on the contact maker.

The function of the condenser is to maintain the instantaneous voltage at a uniform value and so insure a steady reading on the voltmeter, notwithstanding the leakage usually occurring from it, in the interval between successive contacts.

If a Kelvin multicellular voltmeter (preferably dead beat type) is used for the test it will be necessary to obtain a false zero of about 30 on its scale, as the one volt graduations only commence from this point upwards. For this purpose an auxiliary voltage of about 30, which can be supplied by a battery of about 15 small secondary cells, may be used. As the circuit is closed by the contact maker for a small fraction of a second only, the condenser should have a small capacity, otherwise it may not be fully charged. Even though  $V$  and  $C$  are well insulated a certain amount of leakage may occur, depending on the rate of contact—i.e. on the speed of  $D$ . A known steady P.D. should therefore be applied in place of the alternator P.D., and the speed adjusted to the value above, then if there is leakage  $V$  will read differently when the contact is stationary and when periodic; the ratio of these two  $\times V_1$  gives the instantaneous P.D. In the determination of the current curve a low non-inductive resistance should be used, so that its introduction may not affect the existing conditions of the circuit to any appreciable extent. The P.D.s in this case will be small, and can be measured by the ordinary "Null deflection," or balance method on a potentiometer. The amperes per scale division can be found by passing a "known steady direct

current" through ( $r$ ) from a supply in place of  $D$ , the ratio of contact being as above; then known current  $\div$  scale reading = amperes per div.

**Apparatus.**—Alternator  $D$  with its exciting circuit; contact maker  $M$  (p. 619); well-insulated electrostatic voltmeter  $V$  (p. 563), and also  $\frac{1}{2}$  to  $\frac{1}{3}$  m.f.d.

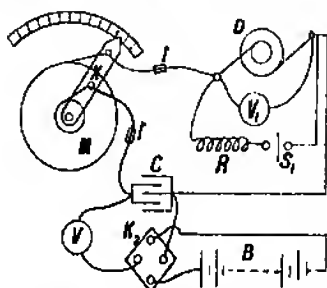


Fig. 170.

condenser  $C$ ; well-insulated battery  $B$ ; A.C. voltmeter  $V_1$ ; A.C.

ammeter  $A$ ; switches  $S$  and  $S_1$ ; load resistance  $R$ , in which the current wave is to be found; non-inductive resistance  $r$ , of such a size as will carry the current without sensible heating; sensitive D.C. galvanometer (p. 569); potentiometer  $PQ$  (Fig. 171), with its slider key  $K_1$ ; E.M.F.— $E$  (2 volts), and reversing key  $K_2$  (p. 585).

**Note.**—All lubricating arrangements must be seen to feed properly when the machines are started.

**E.M.F. CURVE.—Experiments—**

(1) Connect up as in Fig. 170. Set  $X$  to 0 on its scale and measure the auxiliary voltage ( $v$ ) on  $V$  by short-circuiting  $C$  by a wire and afterward removing this.

(2) Start  $D$  and adjust its speed to the normal value, say, also its excitation so as to give about normal voltage on the voltmeter  $V_1$ .

(3) With the speed and terminal P.D. constant, note the *steady* reading on  $V$ , which therefore is a measure of the instantaneous E.M.F. of  $D$  for this position of  $X$ .

(4) Repeat 3 every  $20^\circ$  from 0 throughout the period of alternation ( $360^\circ$ ) by moving  $X$ , noting the points when  $K_2$  is used to reverse the E.M.F. of  $B$ .

(5) Repeat 2-4 when  $D$  is giving a convenient constant current through a suitable *inductive* circuit  $R$ .

**CURRENT CURVE.—Experiments—**

(1) Connect up as in Fig. 171. Set  $X$  to 0 and repeat 2 above.

(2) With  $R$  at its maximum, close  $S$  and adjust the current to the same value as mentioned in 5 above, by means of the exciting current.

(3) With the speed normal and terminal P.D. constant, obtain balance with  $K_1$  so that, on pressing it, no deflection occurs on  $G$ . Note the scale reading ( $d$ ) of  $K_1$ , which

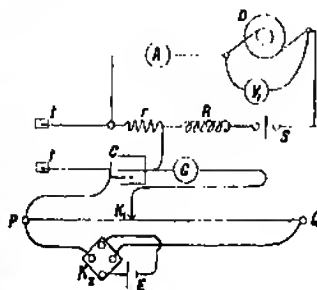


FIG. 171.

G G



therefore is a measure of the instantaneous P.D. at the resistance

(4) Repeat 4 above, and tabulate your results as follows—

Name: \_\_\_\_\_

DATE . . .

Speed of  $B = \dots$  Revs per min

Figure 5 -  $\alpha$  vs.  $\beta$  for  $\beta$  = 100.

Capacity of  $C = \dots$  m.f.g.u.

ALL. B. M. 2. 2. . . . .

Reading of voltmeter  $V_2 = \dots$  volts

Voltage regulation of P.D. (%) =

Resolutor  $A = \dots$  sur  $\mathbb{K}$ 
$$\text{Amplitude} = \frac{1}{\sqrt{2}} \quad (11)$$

Reading of X-meters Angle $\phi$	Total E.M.F. $V$	Nett Ind. E.M.F. $V_1 = V - v$	Reading of I-Q (d)	Actual Ind. E.M.F. at (a d)	Actual Ind. Current through $r$ $A_1 = \frac{a d}{r} = \beta d$	Angle of Phase between $I_1$ and $A_1$
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**Note.**—2  $v$  must either be added or subtracted, on reversing the battery switch, according to whether ( $v$ ) was previously in helping or opposing series. Half the difference between the readings =  $v$ .

It will be obvious that the instantaneous terminal voltage of  $D$  can be obtained in addition to the current, if in Fig. 171  $R$  has a value at least = the maximum value of that voltage;  $PQ$  has a high resistance, and a two-way key be used in place of the permanent connecting wire between  $C$  and  $r$ , so that it will connect  $C$  successively to  $(r)$  as shown, and to the junction of  $R$  and  $S$ , which latter gives the terminal instantaneous voltage.

(5) Plot the E.M.F. and current curves on the same curve sheet, having  $\theta^\circ$  as abscissae in each case and  $V_1$  and  $A_1$  as ordinates respectively, and calculate out from them the  $\sqrt{\text{mean square}}$  of the instantaneous values of  $V$  and  $A$ .

In determining the periodic curves of R.M.F. in a high tension circuit a potentiometer arrangement should be used; the wires going to *D* (Fig. 170) being connected to the ends of a suitable known fraction of a known high resistance placed across the mains, and which can carry an appreciable current, say  $\frac{1}{2}$  to 3 ampere, thus illuminating any error arising from the capacity current of the voltmeter.

(155) Determination of the Periodic E.M.F. and Current Curves of an Alternating Current Circuit. (Ballistically.)

**Introduction.**—Should an electrostatic voltmeter not be available as in the preceding method, a reflecting ballistic galvanometer

$G$  may be used, and it should preferably be of the moving coil d'Arsonval type, so as not to be affected by the stray magnetic fields invariably met with in a dynamo-room. In all other respects the present method is precisely similar to the last.  $K_1$  is a reversing key (Fig. 255) for obtaining deflections each side of zero. When the two-way key  $K$  (Fig. 256) is put to stud 1 the condenser  $C$  is charged to an E.M.F. corresponding to that for the position of the contact arm  $X$  in the period of alternation. On putting  $K$  to 2,  $C$  is discharged through  $G$ , and since the resulting throw is  $\propto$  the quantity flowing out of  $C$ , which in turn is  $\propto C \times V$ , where  $C$  = capacity of the condenser and  $V$  the E.M.F. to which it is charged, we see that the resulting momentary throw on  $G \propto V$ , since the capacity is a constant.

This should be larger the smaller the charging E.M.F. to be measured. The current curve is obtained in a precisely similar manner to that indicated in Fig. 171.

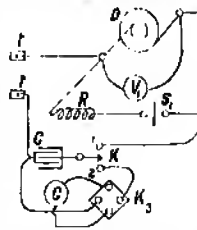


FIG. 172.

### (156) Delineation of Wave-Forms by means of the Duddell Oscillograph.

**Introduction.**—The shape of wave-forms in general, but perhaps more especially those of current and pressure in alternating current circuits, are of the utmost importance to electrical engineers. For instance the efficiency of transformers and a.c. motors, and even the working of the latter, is in some cases seriously affected by the wave-form of the supply. On the other hand, the optical efficiency of the a.c. arc has been found to be 44% higher with a flat-topped E.M.F. curve than with a peaked curve, while transformers work most efficiently on peaked curves. Again the wave-form reveals the presence or otherwise of higher harmonics due to accidental though often avoidable resonance effects, so dangerous in causing the breakdown of the insulation of high-tension electric cables.

The oscillograph itself consists of a highly specialized reflecting d'Arsonval galvanometer having an extremely small periodic

time, when undamped, of from  $\frac{1}{1500}$ th to  $\frac{1}{10000}$ th of a second, depending on the type of instrument.

For all ordinary frequencies the oscillograph is perfectly dead-beat, absolutely free from hysteresis errors, and has practically no self-induction or capacity.

It is therefore an accurate instantaneous ammeter or voltmeter capable of giving a deflection which is at any moment accurately proportional to the instantaneous value of the variable even with frequencies of 300 or more periods per second on any wave-form whether periodic irregular, or non-periodic and whether continuous or alternating.

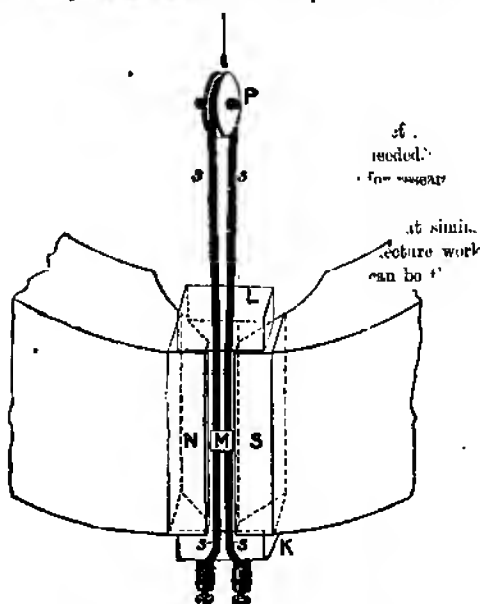
Thus in addition to recording E.M.F. and current waves, such an instrument will indicate the charge and discharge curves of condensers, the changes of P.D. and current on breaking an inductive circuit, the P.D. and current changes in the armature coils of a dynamo or motor, or in the primary of an induction coil or even the very rapid changes when the d.c. are broken. Doubtless it will be employed for a vast number of other determinations as time and necessity arise, but the preceding merely serve to indicate some of the uses to which this highly important instrument has already been put.

### Construction of the Duddell Oscillographs.

The apparatus consists of the galvanometer, combined either with a rotating or vibrating mirror, moving photographic film, or falling photographic plate.

Fig. 173 is a diagrammatic view of the galvanometer part of the instrument showing the principle on which it works. In the narrow gap between the poles *N*, *S* of a powerful magnet are stretched two parallel conductors *s*, *s* formed by bending a strip of phosphor-bronze back on itself over the pulley *P* which is attached to a light spring balance. At the bottom ends the strips are clamped on a block, *K*, while at the top they are held in position by the bridge piece *L*. By altering the tension on the spring stretching the phosphor-bronze loop, the periodicity of the instrument can be varied at will. Each strip or leg of the loop passes through a separate gap (not shown) in the magnetic circuit. The clearance between the sides of the

gaps and the moving strip is but 0.38 mm., and these gaps are filled with a viscous oil, over which is placed a small lens, which is held in position entirely by the surface tension of the oil, and serves in its turn to keep the oil in place. The object of the oil is to damp the movements of the strips. A small mirror



**FIG. 173.—Essentials of the Vibrating System.**

marked  $M$  is attached to the loop, as shown. The effect of passing a current through one of these loops is to cause one leg of it to advance whilst the other recedes, and the mirror is thus turned about a vertical axis. In the high frequency instrument the natural period of vibration of the loop is  $\frac{1}{1000000}$  of a second, and the clearances being, as stated, extremely small, the damping effect of the oil is so great, that the instrument can be relied

upon to give accurate results even when the periodicity of the current to be tested is over 300 periods per second. Small fuses below the loops protect these from injury in case of accidental excessive current. The fuses consist of very fine wires enclosed in glass tubes, which are held in position by spring clamps.

The beam of light reflected from the mirror *M* is received on a screen or photographic plate, the instantaneous value of the current being proportional to the linear displacement of the spot of light so formed. With alternating currents the spot of light oscillates to and fro as the current varies and would thus trace a straight line. <sup>For</sup> To obtain an image of the wave-form, it is necessary to <sup>move</sup> the photographic plate or film in a direction at right angles to the direction of movement of the spot of light. A <sup>second</sup> mirror can be interposed in the path of the beam of light, <sup>the</sup> <sup>second</sup> mirror caused to vibrate or rotate so as to impart to the coils of a <sup>uniform</sup> <sup>motion</sup> a uniform motion proportional to time in a plane at right angles to the plane of vibration of the beam due to the current. The spot of light will now trace out on a stationary screen or plate the time curve of the variation of the P.D. or current as the case may be. If the variations are periodic, as in alternating currents, then the second mirror can be synchronized and the spot of light caused to trace out the wave-form over and over again.

The various methods of examining and recording the wave-forms will be described later.

The Oscillograph is provided with an adjustment for slightly increasing the periodic time and sensibility. This may be done by altering the tension of the strips. This is not advisable, however, as it is liable to spoil the definition of the spots.

Four standard types of Duddell Oscillograph are made and are in common use, namely—

Type I. The Double High Frequency Oscillograph, which is the most sensitive type and has a powerful electro magnetic field. The magnetizing coils are wound in eight sections, and by suitably connecting them the field can be excited direct from any voltage between 25 and 100 volts or from 200 volts with an 8-c.p. lamp in series. The magnetic circuit being saturated, a change of 4% up or down in exciting current only changes the sensibility about 1%. To introduce damping oil, the vibrator cover should be removed, the lens lifted up, the vibrator being held horizontal and a drop

or two of the special oil placed on the gaps over the mirrors. The lens is then lowered into place, the lower edge first, care being taken not to imprison any air bubbles. The temperature of this oil is measured by inserting the bulb of a thermometer at the back of the vibrator.

II. The Single Permanent magnet, and III. the Double Permanent magnet, Oscillographs are similar to one another. In each the electro magnet of Type I. is replaced by a permanent magnet, and the damping oil, which is introduced by means of a small cup at the back of the instrument, is adjusted to give correct damping at 15° C., and practically correct damping between 10° C. and 20° C., so that no thermometer is needed. These two types are portable and can be easily insulated for research on 10,000 volt circuits by placing it on an ebonite table.

IV. The Double Projection Oscillograph is somewhat similar to Type I. and is most suitable for teaching and lecture work. Wave-forms having a total amplitude of 1 metre can be thrown on to a screen.

The above types are *single* or *double* according as they possess *one* or *two strips* respectively. The double or two-strip pattern is practically two single instruments built compactly in one magnetic field and capable of recording simultaneously any two distinct wave forms. A fixed mirror is fitted in addition to give the datum or zero line. Types II. and III. can be arranged in portable form.

### Three Methods are generally employed for Observing and Recording the Movements of the Spots.

1. Visual observation. A rotating mirror is placed with its axis horizontal in such a position that the reflection in it of the moving spot on the screen can be examined; when, owing to persistence of vision, the moving spot will appear drawn out into a bright time curve of the variations which it is required to observe, and this curve can be sketched if required for future reference.

2. Recording by photography. A photographic plate or film

is caused to move rapidly at right angles to the plane of vibration of the beam of light, so that the moving spot traces out on it the required variations.

*The photographic method is very expeditious, and gives permanent records which are free from all errors of a personal nature; it is the only satisfactory method of recording irregular non-periodic variations of P.D. and current.*

3. *Tracing* In this method, which is only applicable to periodic variations, the beam of light from the Oscillograph is reflected by an additional mirror with its axis horizontal before

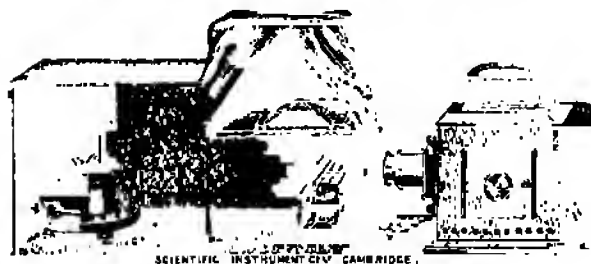


FIG. 174. Type I Double Oscillograph with Synchronous Motor and Tracing Desk.

reaching the screen, and this latter mirror is caused to move uniformly and synchronously with the period of the variations to be recorded. This combination of the two motions at right angles, the one proportional to the instantaneous value of the current through the Oscillograph, and the other to the time, causes the spot to travel continuously along the time curve of variation of the current, which curve, if the frequency is sufficiently high, will appear as a stationary bright line of light. This curve may be recorded by tracing or photography. In the Projection Oscillograph, this stationary line of light can be thrown either on the screen or on the tracing desk.

The arrangement employed for tracing a.c. wave forms which remain fairly constant in shape and frequency and thus obviating the necessity for using photography is shown in Fig. 174. In

it the light from the Oscillograph mirrors is reflected vertically by a small mirror which is made to vibrate synchronously by means of a specially designed alternate current motor. The light is thrown on to a curved screen, on which tracing paper is held by means of a clip and on which the wave-forms appear as

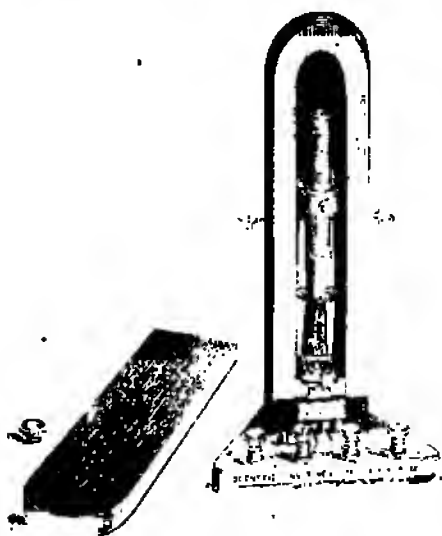


FIG. 175.—Type III. Double Permanent Magnet Oscillograph.

stationary curves of light, and may be traced by hand. The small mirror is vibrated by means of a cam attached to the motor shaft. The cam is so arranged that the mirror moves uniformly for about  $1\frac{1}{2}$  complete periods during which the wave-form is observed; it then returns rapidly to its starting point during the remaining  $\frac{1}{2}$  period. During the half period of return motion, the light is cut off from the Oscillograph by means of a sector fixed to the motor.



The Oscillograph shown in Fig. 175 can of course be substituted for that shown in Fig. 174, the tangent screw heads *a*, *a'*, Fig. 175, being for the purpose of bringing the spots of the Oscillograph to zero on the screen.

**The Synchronous Motor.**—Seeing that this must run dead synchronously with the wave-forms to be recorded, it should be supplied from the same circuit.

*To start the latent type of motor*, connect the three terminals on it to the phase-splitting board by means of the three-way flexible lead attached to the latter. Care must be taken to connect the wires to the terminals correspondingly marked, the remaining two terminals on the phase-splitting board being connected to the a.c. supply having a P.D. of 100 to 120 volts with any frequency between 30 and 100 ~ per sec.

See that the armature of the motor is quite free by turning the milled head, and that the bearings are well oiled, then after pushing the movable core of the choking coil in as far as it will go, close the switch. Now give the armature a start by sharply twisting the milled head on its spindle at the vibrating mirror end in the clockwise direction, when it should continue to run and increase in speed up to synchronism.

If the motor does not attain synchronism (indicated by the "beats" in the sound emitted), draw out the core of the choker little by little until a constant rhythmic hum is given out.

The position of the core for synchronism depends on the wave-form and frequency, being farther out the higher the latter. If the core is too far in, the motor will not attain synchronism, and if too far out the motor will take too much current and get hot.

It might be necessary to remove the load from the motor at starting by pressing back the mirror so as to lift the "follower" of the cam.

The wave-forms will have more than one complete period, and will move to and fro on the tracing disc or screen if the motor is running below synchronous speed.

### Method of Connection of Oscillographs to the Circuits to be Investigated.

The P.D. required to work the Oscillographs when fuses are used in series with the strips is only 1 to 1.5 volts. For current curves a non-inductive shunt  $R_2$  should be placed in the main circuit and connected as shown in Figs. 176 and 177. The low resistance  $R_3$  serves to adjust the sensibility to a round number of amperes per millimetre. An Ayrton-Mather shunt giving six sensibilities for currents from 1.5 to 60 amperes is made for this purpose. When the sensibility is adjusted by altering  $R_3$  to a round number of amperes per millimetre for any one of the

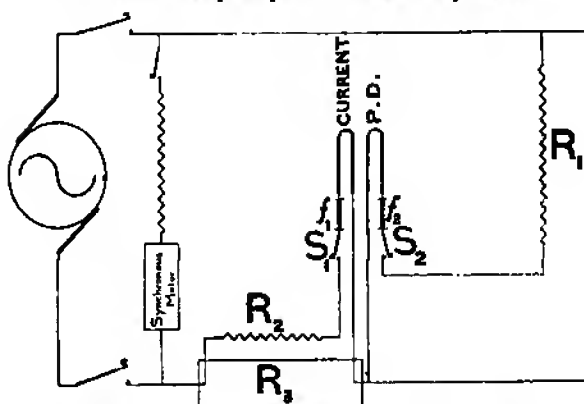


FIG 178.—Diagram of Connection of Oscillograph to Low Tension Circuit.

sensibilities, all the other positions of shunt are simple multiples of the same; thus with Oscillographs Types I, II, and III, the sensibilities may be 0.05, 0.1, 0.2, 0.5, 1.0, 2.0 amperes per millimetre. Standard Potentiometer shunts constructed for a drop of 1 to 1.5 volts can also be used in place of  $R_2$ .

For P.D. measurements up to 250 volts a non-inductive resistance  $R_1$  is placed in series with the strips, Fig. 176, which is adjusted to give a round number of volts per millimetre deflection. The switches  $S_1$ ,  $S_2$  and fuses  $f_1$ ,  $f_2$  should be arranged as

shown in the diagram so that no P.D. can exist between the P.D. and current strips due to their action.

For P.D.s up to 15,000 volts the arrangement shown in Fig. 177 is much safer.  $R_1$  consists of several specially wound 10,000 ohm resistance frames joined in series and giving about 7 to 10 ohms for each volt, so that on a 10,000 volt circuit  $R_1$  would be 70,000 to 100,000 ohms;  $R_2$  is a 100 or 200 ohm coil forming with  $R_1$  a potential divider;  $R_3$  is a resistance to adjust the sensibility

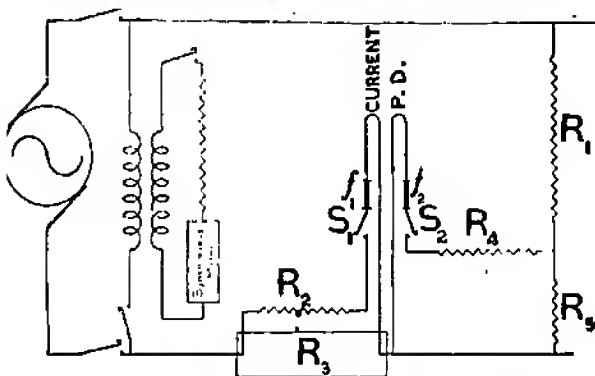


FIG. 177.—Diagram of Connection of Oscillograph to High Tension Circuit.

to a round number of volts per millimetre deflection. The same resistance box as is used for  $R_1$  in Fig. 176, is suitable. When P.D. curves only are being recorded then  $R_5$  should be connected at that point in  $R_1$  which has the least potential above earth. All the resistances  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$  and  $R_5$  must be insulated so as to stand four or five times the working voltage to earth. Unless the side of the circuit containing  $R_5$  is permanently connected to earth it is better not to use any switches or fuses in the Oscillograph circuit as shown, and permanent magnet Oscillographs Types Nos. II, or III, should be used. It is also advisable to connect one terminal of the strips to the frame so as to screen it from electrostatic effects. On high voltage circuits the synchronous motor if used is best supplied through a suitable transformer.

When using the double Oscillographs the two pairs of strips should be so connected to the circuit that it is impossible under any circumstances that a higher potential difference than 50 volts should exist between one pair of strips and the other, or between either pair and the frame.

The Oscillographs should be calibrated with continuous currents and the resistances  $R_1$ ,  $R_2$ ,  $R_3$  adjusted so that one mm. deflection corresponds to a convenient number of amperes or volts, as the case may be.

The following table gives some useful approximate data for the various forms of Duddell Oscillographs.

TABLE VII.

	Double High Frequency Oscillograph.	Single Permanent Magnet and Portable Oscillograph.	Double Permanent Magnet and Portable Oscillograph.	Double Permanent Magnet and Portable Oscillograph.
Resistance of Field Coils in series at 50° C. . . . .	360 ohms.	—	—	650 to 700 ohms.
Normal exciting current with the coils in series . . . . .	0.28 ampere.	—	—	0.27 ampere.
Working Temperatures for coils & damping with the oil supplied . . . . .	25° C. to 35° C.	10° C. to 20° C.	10° C. to 20° C.	30° C. to 35° C.
Normal tension on strips . . . . .	8 mpa.	1½ mpa.	2½ mpa.	6 lbs.
Residue Time (measured) with the above tension . . . . .	1.5 sec. to 1.8 sec.	1.5 sec. to 1.8 sec.	1.5 sec. to 1.8 sec.	1.5 sec. to 1.8 sec.
Normal Scale deflection . . . . .	50 cms.	50 cms. (25 cms. when used as Portable Oscillograph)	50 cms.	300 cms.
Sensitivity with the above tension, normal exciting current and scale distance with damping off in instrument . . . . .	200 mm. per ampere.	320 mm. per ampere.	200 mm. per ampere.	50 cms. per ampere.
Normal Working Current in strips for alternate current wave-forms . . . . .	0.05 to 0.10 ampere.	0.05 to 0.10 ampere.	0.05 to 0.10 ampere.	0.5 ampere.
Resistance of strips without fuses and connections . . . . .	about 5 ohms.	about 5 ohms.	about 5 ohms.	about 1 ohm.
Do. do. with one fuse and connections . . . . .	about 10 ohms.	no fuses.	no fuses.	about 1½ ohms.

### (157) Determination of the Efficiency of an Electro-Motor-Fan Set.

**Introduction.**—The very extensive use to which the electrically driven fan is put, coupled with the large number of combinations of different types of motors and fans in use at the present day, makes it desirable to obtain some measure or gauge of the efficiency of such an electric fan as an air circulating device.

From a commercial point of view, the utility of a fan can best be judged by knowing (1) the quantity of air, reckoned say in cubic feet, passed by the fan in unit time, say 1 minute; (2) the power required to drive the fan to give this. Also, from a mechanical point of view, the speed of the fan under these conditions, and, as a matter of scientific interest, the pressure of the air thus passed.

In order to carry out the test, it will be necessary to provide the fan with an air conduit for the purpose of restricting the current of air to a definite path. This may very simply and conveniently consist of a tubular casing of either circular or square cross section, open at both ends, and from three to four diameters long. The fan must just fit into one end, and any crevices due to loose fitting between the sides of the conduit and fan must be filled in air-tight, so that the only path for the air is through the fan itself.

The determination of the pressure of the draught through the conduit *CD*, but which, however, is not essential to the test, and merely of interest, can be determined by a special form of water or spirit gauge *G*.

Since the pressure of the draught is very small, an ordinary vertical *U* pressure tube would hardly indicate it, and not sufficiently accurately for any practical use. To measure such small pressures, the gauge, in the present instance, may conveniently take the form of a slanting *U* glass tube about  $\frac{1}{4}$ " to

$\frac{1}{8}$ " bore, one limb  $L$  of which is extended and bent into the form shown as  $LO$ , the end  $O$  being bent so as to face the incoming draught of air from the end  $C$  of the conduit.

If now this U tube contains coloured alcohol, any slight pressure at  $O$  will cause a difference in level of the liquid in the two limbs, the vertical distance between the ends of the columns being a measure of the pressure at  $O$ . Thus even though this is very small, the end of the liquid column in either limb may have moved through a considerable distance, which increases as the angle of slope ( $\theta$ ) gets smaller. Hence if the tube is provided with a scale and calibrated, it can be made to read small fractions of an inch pressure of water, etc.

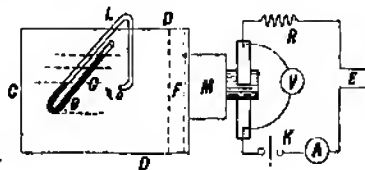


FIG. 173.

A little cotton wool placed in each end of the tube helps to damp the motions of the liquid column caused by rapid fluctuations of air pressure.

In order to obtain the volumetric discharge of air for any particular speed of the motor  $M$ , the velocity of the propelled air must be obtained by means of a rotatory anemometer placed in different positions in the cross section of the conduit some little distance from the end  $C$ , the instrument being supported at the end of a stout wire or rod so as not to alter the flow of air. From the various readings a mean may be obtained for the whole section.

Now let  $v$  = mean velocity of the air in feet per minute as given by the anemometer, and let  $s$  = area of cross section of the conduit in square feet, then the volume of air discharged per unit time, i.e. number of cubic feet of air per minute =  $vs$ ; this will vary with the speed of the motor.

Let  $w$  = weight in lbs. of 1 cubic foot of air at the barometric pressure and temperature of the room in which the test is made (see table, p. 650), then  $W = wvs$  = the weight in lbs. of air discharged per minute; but the kinetic energy of a mass ( $m$ ) lbs. moving with a velocity  $v$  feet per second =  $\frac{1}{2}mv^2$  foot-pounds, and this is a measure of the work done.

Hence the work done on the air =  $\frac{1}{2}wvs^2 \div g$  foot lbs.

$$\therefore \text{H.P. developed} = \frac{\frac{1}{2}Wv^2}{32.2 \times 33000} = \frac{wvs}{2 \times 32.2} \times \left(\frac{v}{60}\right)^2 \times \frac{1}{33000}$$

**Apparatus.**—Motor  $M$  with its attached fan  $F$  to be tested; suitable conduit  $CD$ ; anemometer; air pressure gauge  $G$ ; voltmeter  $V$ ; ammeter  $A$ ; switch  $K$ ; rheostat  $R$  (p. 600) and source of electrical supply  $E$ ; speed indicator for obtaining the speed of the motor.

**Observations.**—(1) Connect up as shown in Fig. 178, and adjust the instruments to zero if they require it. See that all lubricating cups are filled slowly and properly.

(2) With  $R$  at its maximum, close  $K$ , and adjust the speed of the motor  $M$  to the lowest convenient amount, then note the readings of  $V$ ,  $A$ , speed, anemometer, and gauge  $G$ .

(3) Take the anemometer reading at different positions in the cross section of the conduit at this speed of  $M$ , and take the mean.

(4) Repeat 2 and 3 for twelve or fifteen different speeds of the motor, rising by about equal increments to the maximum permissible, by varying the rheostat  $R$ , noting simultaneously the readings of all the instruments at each speed. Tabulate your results as follows—

NAME . . . . .
DATE . . . . .

Electro-Motor: No. . . . .		Type . . . . .	Maker . . . . .	Normal Volts . . . . .	Amps . . . . .	Speed . . . . .		
Fan: No. . . . .		No. of blades . . . . .						
Suctional Area of Conduit = . . . sq. ft.				Weight of 1 cubic foot of air at time of test = . . . lbs.				
Mean anemometer reading (ft. per min.)	Pressure of Draft in inches	Discharge in cub. ft. per min. (45)	Speed of Motor revs. per min.	Volts $V$	Amps. $A$	Horse Power		Efficiency of Fan $\frac{P_2}{P_1}$ $\approx 100 \frac{P_2}{P_1}$
						absorbed $\frac{VA}{746}$	developed $\frac{W}{33000}$	

(5) Plot the following curves on the same curve sheet having (a) the speed in revolutions per minute of the motor, (b) H.P. absorbed by the motor as abscissae, with the volume of air discharged per minute as ordinates in each case; also between (a) as abscissae with (c) the mean velocity of the air draught as given by the anemometer, (d) the H.P. absorbed in the transference of air as ordinates in each case; lastly, between efficiency as ordinates and speed as abscissae.

### (158) Determination of the Commercial Efficiency of a Gas Engine-Dynamo Generating Set.

**Introduction.**—It is most desirable that any generating unit such as the above should be tested at various loads or electrical outputs in order that the best running conditions may be discovered and the performance generally of the unit observed.

This is done by "indicating" the engine at the various electrical load outputs desired, and so finding the relation between the total power exerted on the piston of the engine, commonly termed its indicated horse-power (I.H.P.), and the corresponding power utilized or developed by the generator in the external circuit, which may be reckoned in  $\frac{\text{Watts}}{746}$  or electrical horse-power (E.H.P.).

In order that the cost of running at any given electrical output per hour (say) may be determined, it will be necessary to measure the *volume of gas used* in the engine, which can usually be done easily enough, as nearly all gas engines are provided with separate gas-meters on the inlet pipe of the engine. Should, however, this not be the case, the test must be made when all gas-jets are out and the readings on the main meter recorded.

The *jacket water*, or volume of cooling water passed through the water jacket of the cylinder of the engine, should be measured, and this can best be done by a water-meter inserted in the inlet water-pipe. If such a meter is not available, a fairly large tank can be used (the volume of which can be calculated) to supply the



water jacket, then the time taken to empty the calculated known volume of water will enable us to get what is required. If the temperature of the inlet and outlet water of the jacket is taken, the heat removed from the cylinder in thermal units can at once be deduced, knowing the volume of water passed in a given time.

The engine must be provided with a stop-cock in communication with the interior of the cylinder, and into the outer end of which the nipple of the indicator is screwed. This indicator may be of the Richards' type, and, if the gas engine is running at a high speed, the indicator should be a high speed one. If the diagrams taken by this indicator in such cases are not shortened, a stronger drum-spring will be needed to get over the effects of inertia in the drum which carries the card.

If the engine has an ordinary double (Otto) cycle and gets the maximum number of explosions possible, which would occur when it is running at or near full load, then the speed in revolutions per min.  $\div 2$  will give the number of explosions per min. If, however, the gas engine is running on light loads it will "miss" an explosion frequently, in which case, since the number of such per min. is a factor of the I.H.P., they must be counted separately, either mentally or automatically by an attachment or counter actuated by the inlet gas-valve lever.

Furthermore, in order to obtain the total cost of electrical energy delivered at the switch-board, we must know the amount of oil, cotton waste, wages, and interest on depreciation and first cost of the plant for the period over which the run extends; these items, however, pertain merely to what we may term the economic efficiency of the plant.

The electrical power developed by the dynamo can be taken up either in the apparatus on the circuit to be supplied, or in suitably designed water rheostats having ample plate area to avoid variations in the output. This may take the form of a rectangular water-tight wooden trough, having a fixed zinc, iron, or copper plate at one end, connected to one terminal of the dynamo, and a similar movable plate, capable of being moved to a considerable distance from the fixed plate, thus enabling the current output to be varied; this plate is perforce connected to the other terminal of the generator.

The mean effective pressure  $P$  in lbs. per sq. in. during the

explosion, which is required in the calculations, is calculated, from the indicator diagrams taken, in the manner described on pp. 471 and 530.

**Note.**—The effective area of each plate of the water rheostat should be something like 4–9 sq. ft. for currents of about 600 amperes.

**Apparatus.**—Gas engine dynamo set *D* to be tested, of which the gas engine is not shown; indicator (p. 531) and reciprocating lever gear for rotating the card drum; tachometer; voltmeter *V*; ammeter *A*; trough rheostat *T* for absorbing the electrical output from *D*.

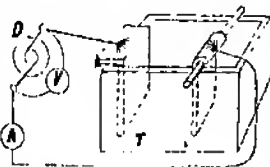


FIG. 179

In addition a "cut-out" and switch are desirable in the main circuit, and a water-

meter with necessary separate gas-meter for the engine.

**Observations.**—(1) Connect up the electrical circuit as in Fig. 179, and adjust all instruments to zero. Fill *T* with water in which a few handfuls of washing soda have been dissolved and set the plates at the extremities of the rheostat.

N.B.—The plates may be provided with massive terminals for connection to the main leads, otherwise the ends of these latter should be spread out, fan-wise, and soldered to the plates.

(2) Measure approximately how much oil is required to fill all lubricators in use, which must be set to feed properly just before starting the trial.

Insert the most suitable spring in the indicator and a card on the drum, then screw the indicator to the cylinder cock and connect to the reciprocating gear.

(3) Start the "set" up to its normal speed and take an indicator diagram from the engine with *D* on open circuit.

(4) At a noted instant simultaneously read all the instruments and meters, then quickly switch on and adjust *A* to full load and take an "engine card" again.

**Note.**—At least four observers will be required for the trial.

(5) Simultaneously read all the appliances every twenty minutes



station engineers to curtail the amount of floor area required for a given station and to avoid the loss of power and trouble inseparable from driving by belts and ropes. In order to determine the combined efficiency of a generating unit, whether direct coupled or otherwise, we require to measure the useful or nett electrical output, which can be done with the aid of an ammeter, voltmeter, and one or more suitable rheostats in the manner described in the earlier pages of this book.

In addition we must know the gross or total H.P. exerted by the piston of the engine, usually termed the Indicated H.P. This can be determined by aid of the *engine indicator*, for the detailed theory of which the reader is referred to special "works" dealing with such *indicators* almost entirely. There are, however, some important details connected with the use in general of the various forms of these instruments, which may with advantage be mentioned here, but otherwise it will be assumed that the theory, construction and action of the engine indicator is understood.

*Relation between length of indicator diagram and engine speed.*—It must be carefully remembered that as the paper drum of the indicator is rotated by a reciprocating motion from the piston or cross-head of the engine, its inertia at the higher speeds may introduce errors in the diagram; in other words, its motion may continue, from this cause, beyond what actually represents the true driving motion. To minimize such an error the angular motion of the drum must be reduced, and consequently a shorter diagram obtained as the speed increases, in order to insure a true and properly proportioned diagram.

In this connection it may be noted that for *speeds up to 200 revs. per min.* the driving of the drum should be so arranged that its angular motion gives a diagram about  $4\frac{1}{2}$ " long, and this should be made to diminish almost inversely proportional to the increase of speed. Since in addition increase of speed will require a stronger piston spring, the height and length of diagram will decrease in about the same proportion for increase of speed, thus giving a properly proportioned and accurate diagram.

*Gearing of Engine Indicators.*—In order that an accurate diagram may be obtained it is all-important that the reducing-gear for driving the drum should reduce the piston motion in

exactly the same proportion at any and every part of the stroke. For such gears the reader is referred to works dealing with the subject of engine indicators. In the use of the indicator great care should be taken to keep it free from all dust and well oiled with watch oil, as the least friction in the cylinder or multiplying levers may cause a distortion of the diagram, the boiler pressure and engine speed will determine what strength of spring is to be used in the cylinder, and the lighter this is, the higher the diagram and the more accurate the measurement, providing inertia effects are absent.

The engine piston must of course never be allowed to close the outlet pipe between the engine and indicator cylinders, hence the latter should be screwed on to a cock at the end of the engine

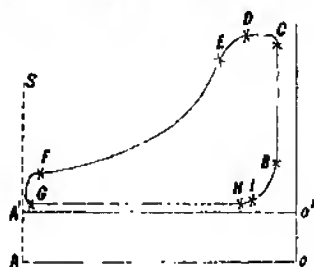


FIG. 180.

of its piston in communication with the atmosphere by opening the stop-cock so as to cut off all steam from the cylinder of the engine and allow the air to enter underneath the indicator-piston. The pressure both sides of this latter will thus be the same and equal to that of the atmosphere, consequently if the pencil be lightly pressed against the moving card, the horizontal straight line  $O'A'$ , termed the *atmospheric line*, will be described.  $OA$  is the *absolute zero line*, parallel to  $O'A'$ , and drawn below it at a distance representing, to the scale of the diagram, the atmospheric pressure at the time of the test.

In Fig. 180  $B$  is the point of admission of steam to the engine cylinder,  $D$  the point at which the slide-valve begins to close,  $E$  the point at which it is quite closed. From  $E$  to  $F$  the admitted

steam is expanding, and at *F* the release begins, being completed at *G*. The exhaust-valve begins to shut at *H* and is quite shut at *I*, the steam still left in the cylinder being compressed between *I* and *B*. The rounded corners, such as *DN* and *FG*, show the slow acting of the steam valves in closing and opening the steam ports, which is called *wire drawing*. In the ideal engine these rounded corners would become sharp ones.

*Determination of I.H.P. from the diagram.*—Referring to the diagram, Fig. 180, the horizontal distance between the extreme points of the diagram, i. e. between the vertical lines *A'S* and *BC*, represents the stroke of the engine piston in feet. The ordinates of the diagram perpendicular to the atmospheric line *OA'* represent to the scale of the indicator spring used the pressures of the steam in lbs. per  $\square'$ .

If the scale of the indicator spring used in taking the diagram =  $\frac{1}{30}$ , each inch of the ordinates represents 30 lbs. pressure per square inch, consequently each square inch of the diagram represents  $\frac{1}{12} = 2\frac{1}{2}$  ft. lbs. The whole area of the diagram will therefore represent the indicated work in ft. lbs. per square inch of engine-piston, done on one side of it, during one stroke. Since the pressure exerted by the steam on the piston varies at different parts of the stroke, we must know the mean effective pressure for the complete stroke. This is found by *dividing the area of the diagram by the base line*, both being reckoned in inch units. The result is the value of the mean ordinate of the diagram or mean effective Pressure ( $P_m$ ) in lbs. per square inch of piston area.

Hence if *L* = length of stroke in feet, *A* = piston area in square inches, and *N* = number of revs. per min. which the engine is making, then the I.H.P. =  $\frac{2 P_m LAN}{33000}$

**Apparatus.**—Generating set to be tested; engine indicator (p. 531); speed indicator; planimeter (p. 528); ammeter; voltmeter; rheostat for absorbing the load from the generator (p. 467), and a switch.

**Observations.**—(1) Connect the ammeter, rheostat and switch in series with one another and with the generator, also the voltmeter across the terminals of the machine, and open the switch.

(2) Disconnect the generator and engine and start the latter, running alone for some little time before making a test. Prepare



**Note.**—The value of  $P_m$  in the above table is the *mean* of the *means* of the worked-out results for the two ends of the cylinder of a single cylinder engine. In the case of a compound or triple expansion engine, the I.L.P. can be found from the diagram taken from *either cylinder* as follows—

Sum the products of  $A$  and  $P_m$  for each cylinder ( $P_m$  being given by the diagram for that cylinder found in the usual way) and divide by the  $A$  for that cylinder from which the particular diagram under consideration was taken. Thus if  $A_2$  = piston area in sq. ins. of, say, the "intermediate cylinder" of a triple expansion engine, the mean effective pressure to be used in the formula, say  $P_m' = \frac{\Sigma(P_m A)}{A_2}$  where  $\Sigma$  indicates the sum of the products for the I.L.P. intermediate and I.P. cylinders.

The value of the mean effective pressure as obtained from any particular indicator diagram can be obtained by the aid of the planimeter, the use of which in measuring the area of the diagram is described on p. 570.

### General Observations on Jointing Electric Lighting Cables.

Good and reliable joints both in *core and insulation* can only be made with practice, care, and attention to the following essential details:—All joints in conductors must be as mechanically and electrically perfect as possible, for they are in most cases a source of weakness in an installation.

**The Joint.**—That of the metallic core should have a conductivity not less than that of an equal length of the ordinary core, if possible, and to obtain this care must be taken not to *nick* the copper cores of the cables to be jointed either with the paring knife or pliers, which not only reduces the conductivity, but causes the wire of the strand so nicked to break off at once if bent at that point. Before making the joint, all the wires must be *straight* and thoroughly *cleaned* with fine emery cloth, care being taken not to remove the tinning of already tinned wires. The cleaned wires may preferably be re-tinned with the soldering-iron, and must be handled as little as possible, even with clean hands.



No joint will ever solder properly unless it is quite clean throughout, and in a *hot, clean*, and well-tinned soldering-iron.

**The Soldering-Irons.**—These must be properly grooved to take the size of joint to be soldered, and should never be allowed to get too hot and “burn.” This always gives rise to an excessive lurid *green* flame, and is not only injurious to the “copper bit,” but burns all the tinning off them, thereby giving extra labour and wasting time in re-tinning. Irons may be cleaned with either sal ammoniac, emery cloth, or carefully with a suitable file. Salts or soldering fluid may be used as a flux in tinning them. Irons should be *well tinned*, and hot enough when used to be unbearable when placed about  $1\frac{1}{2}$ ” from the cheek. They should be wiped when taken out of the stove before applying to the joint. *Quick soldering* is essential, as continued application of heat seriously weakens copper wire and makes it brittle. Too great a heat causes solder to “rot” and become useless.

**Solder.**—This should be in thin sticks, and should contain enough tin to enable one to hear it crinkle when bent double close to the ear.

**Flux.**—Nothing but *resin* (applied in the lump) should be used in soldering copper joints. All liquid fluxes and other substances containing corrosive ingredients should be avoided if the joint is required to remain unimpaired with time.

**Insulation.**—Great care should be taken to make the insulation of the joint as nearly as possible equal to that of the rest of the cable. In rubber-insulated cables the braiding or taping is removed from the rubber without nicking it, and the pure I.R. strip wound with *lap winding* over the joint and *tapered* ends of the rubber thus bared. I.R. solution is now rubbed over the joint, but must never touch the bare joint. The taping should be done tightly, and be quite solid when completed.

### (160) Detailed Instructions for Jointing Electric Light Cables.

**Introduction.**—For successful and efficient jointing the following remarks must be rigidly adhered to—

(1) In *having* any wire or cable preparatory to making a joint,

great care must be taken not to nick any one or more of the copper wires forming the core, which would not only cause the wire so nicked to break off on bending it once or twice, but would also diminish the sectional area of the cable and so also its current carrying capacity.

(2) In cleaning the copper wires of the core *fine emery cloth* must be used and all dirt removed, but as little as possible (if any) of the original tinning.

(3) Just *sufficient* and *no more* cable must be bared as will make a satisfactory joint, considerations of the cost of insulating materials, and particularly of the ultimate insulation resistance of the joint, making it imperative to keep the dimensions of the joint, in the matter of length, a minimum.

(4) Cleanliness is of vital importance in the actual winding or making of the joint, and a few extra seconds spent in insuring this will almost invariably save many minutes, much solder and soldering flux in the end, and even possibly the necessity for a second attempt at the whole joint.

(5) A badly made joint, or a badly insulated one, is a source of considerable danger in an electric light installation.

(6) Too much attention cannot be paid to the soldering iron, as it is perfectly hopeless to attempt to solder a joint with—a dirty iron, badly tinned iron, or a soldering iron that is not hot enough.

#### COURSE IN JOINTING ELECTRIC LIGHT WIRES, CABLES, AND MAINS.

The following series of joints constitute a course in the actual practice of "*jointing making*" which the author instituted in his department at The University, Leeds. They comprise practically all the principal distinctive types of joints commonly met with in practice, and which might be required to be made by *any ordinary wireman*—

No.		No.	
1	Twist-Joint between two	No. 18	S.W.G. insulated E.L. wires.
2	" " " "	No. 14	" " " "
3	" " of a No. 18 on to a No. 14	" " " "	" " " "
4	" " of a No. 14 on to a No. 7/18	" " " "	" " " cable.
5	Bittang's Joint between two	No. 10	S.W.G. bare copper wires.
6	Scarf " " " "	No. 6	" " " "

No.		No.
7	Twist-Joint between two	7/18 S.W.G. insulated E.L. cables.
8	T- " " "	No. 7/18 " " " "
9	Twist- " " "	No. 7/14 " " " "
10	T- " " "	No. 7/14 " " " "
11	Twist- " " "	No. 19/16 " " " "
12	T- " " "	No. 19/16 " " " "
13	Twist- " " "	No. 37/16 " " " "
14	T- " " "	No. 37/16 " " " "
15	Twist- " " "	No. 7/16 S.W.G. insulated lead-covered E.L. cables.
16	T- " " "	No. 7/16 S.W.G. insulated lead-covered E.L. cables.
17	Twist- " " "	No. 16 S.W.G. insulated gutta-percha-covered wires.
18	T- " " "	No. 16 S.W.G. insulated gutta-percha-covered wires.
19	Twist- " " "	No. 19/16 and a No. 7/18 S.W.G. insulated electric light cables.
20	Slanting T-Joint between two	No. 19/16 S.W.G. insulated electric light cables.
21	Twist-Joint on a large concentric lead-covered electric light main.	

NOTE.—No. 5 is a joint used for aërial telegraph and telephone lines. Nos. 17 and 18 are joints used for telegraph work principally.

#### Twist-Joints Nos. 1 and 2.

**To prepare.**—Carefully bare, with a *sharp knife*, about  $1\frac{1}{2}$  inches of the ends of the two wires to be jointed. This must *not* be done by a cut perpendicular to the wire, but by a short slicing motion round the wire, when the piece of insulation will in most cases come off whole with a suitable pull.

Clean each bared wire with fine emery cloth, straighten and place them across each other, then lightly gripping them at the crossing point with a pair of pliers, bend one free end round the other wire. Do this with the other end and finally straighten and trim the ends up close, so that they do not project outwards, as they are then liable to pierce the insulation.

**To solder.**—Place the joint in a well-tinned groove of the iron containing solder, then when hot just touch with a lump of resin and draw a thin stick of solder over the joint. This usually suffices, but if not, repeat the operation, using very little resin. The soldered joint must leave the iron quite *bright* and without any globules of solder hanging to the underside of it. The soldered joint should appear as in Fig. 181.

**To insulate.**—When cool, taper the ends of the insulation, and

starting from over the rubber of the wire, wind the joint over with a spiral *half overlap* of pure I.R. strip (para tape) to the other end, gently stretching the tape all the time so as to obtain a *firm (not spongy)* layer of I.R., which, since it is wound in half



FIG. 181.

overlap, constitutes a double layer. Apply I.R. solution to the outside of this I.R. lapping (on no account next to the copper joint) and rub evenly all over the lapping with the finger. Next, when the spirit has evaporated out of the rubber solution, wind on a similar layer of black prepared rubber tape, overlapping the outer insulation of the wire at each end, and sealing the ends down with solution. Lastly, paint the outside of the joint with black waterproof varnish and allow it to dry.

#### T-JOINTS Nos. 3 and 4.

**To prepare.**—Carefully bare about  $1\frac{1}{4}$  to  $1\frac{1}{2}$  inches of the wire to be tapped (the larger of the two) and clean with *fine* emery

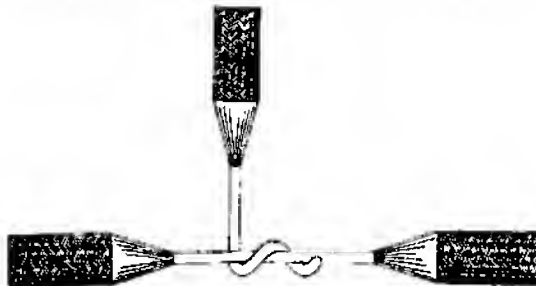


FIG. 182

cloth. Bare about  $1\frac{1}{4}$  of the end of the other wire, clean and straighten, then placing this across the other wire twist it round two or three times to produce the joint shown in Fig. 182, and trim

the end so that it does not project to any extent. Solder in the manner described for joints 1 and 2.

**To insulate.**—Proceed as in these last named joints, but on arriving at the T with each serving, carefully branch off down it and back, stretching the tapes more tightly to allow for increased thickness of insulation; finally, continue along the remaining straight portion of the cable, and varnishing over the last layer of tape. Considerable care is required in insulating a T-joint, as it is more difficult to get round the corners (*i.e.* angles) of the T with the tapes, and these parts therefore are most liable to imperfect insulation.

#### BRITANNIA-JOINT No. 5.

**To prepare.**—Gently straighten the ends of the wires to be jointed by lightly tapping them with a mallet on the anvil. Clean each with fine emery cloth, tin them both for a distance of about 2 inches from the end, and bend sharply round the tips of



FIG. 183.

their ends. Next place them together with the bent ends pointing in *opposite* directions, and with an overlap of about 2"; then bind them together with about No. 20 tinned copper binding wire as shown in Fig. 183. Trim off the ends of this wire, and solder the whole into one solid mass as described in joints Nos. 1 and 2.

#### SCARF-JOINT No. 6.

**To prepare.**—Gently straighten the ends of the wires to be jointed by lightly tapping them with a mallet on the anvil. Clean each for a distance of about 1 inch from their ends with emery cloth.



FIG. 184.

Next scarf them with a flat file as shown in Fig. 184, so that

they taper to thin edges and fit. Then tin them both, wiping off nearly all the superfluous solder by a clean cloth. Now warm the ends up, and when the surface solder on the scarfed portions is melted, place them together to form a continuous wire and



FIG. 185.

allow to cool. Bind the joint with No. 18 or 20 tinned copper wire for about  $\frac{3}{4}$ " from the centre each way as in Fig. 185. Lastly, trim the ends of the wire and solder into one solid mass, care being taken to *just keep* the scarfed ends in gentle contact while soldering and until set.

#### TWIST-JOINTS NOS. 7 AND 9.

**To prepare.**—Carefully bare about 4" of the two ends to be jointed with a sharp knife and a slicing motion (not a cutting one perpendicular to the cable).

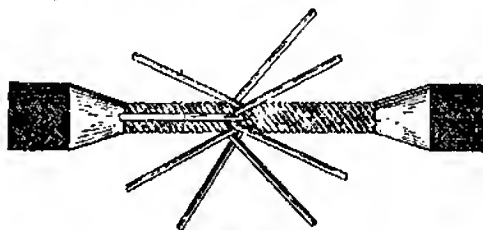


FIG. 186.

Separate out each wire and clean them all with fine emery cloth carefully, so as not to remove any tinning if possible. Straighten each, cutting off half the centre wire of each cable, and then re-twist the outer six up to the end of the centre wire with about the same pitch as the rest of the cable itself in both cases, arranging them so that the six free straight ends form a cone with its apex at the end of the centre wire.

Now push the cones together, so that the six wires of each

interlace alternately, and their apoxes touch as shown in Fig. 186, i. e. the two middle wires butt against each other. Now press down the left-hand set on to the cable, and hold tightly in the hand. Then wind with the other hand the remaining six wires of the other cable, *one by one*, by, say, half a turn at a time, and evenly to, say, 1 or  $1\frac{1}{2}$  inches from the centre, snipping off each what is not wanted, and trimming the ends so as not to project outwards. Repeat these operations with the other half, and



FIG. 187.

finally trim the centre also by pressing with the pliers, but not scraping the cable in so doing.

N.B.—The joint may then appear like Fig. 187 or 188, preferably the latter, which makes the neater joint and is, as seen, wound in the same sense as the main cable.

**To solder.**—Place in the well-tinned groove of a fairly large soldering iron and run in some solder around it, then when quite hot just touch the joint for merely an instant with a lump of



FIG. 188.

resin, and draw a stick of solder over the joint. This, as a rule, will suffice to cause the whole joint to become tinned; if it does not, repeat. When properly tinned the joint should leave the iron in a bright state, and with no globules of solder hanging to the underside of it, and should be one solid mass.

**To insulate.**—When cool taper the ends of the insulation, and starting over the rubber of the cable, wind on spirally with a half overlap two layers of pure I.R. tape in opposite directions and with enough tension to make the insulation firm and solid. The end of this tape is fixed down by I.R. solution, which is also

applied to the outside of the rubber-taping all over the joint by means of the finger. When the spirit has evaporated repeat the above winding process with two layers of black prepared rubber tape overlapping the outer braiding of the cable. Lastly, varnish the joint all over with black waterproof varnish and allow it to dry.

#### T-JOINTS NOS. 8 AND 10.

**To prepare.**—Carefully bare about  $2\frac{1}{2}$ " to 3" of the cable to be tapped. Clean the outside of the stranded core with fine emery cloth and retin well.

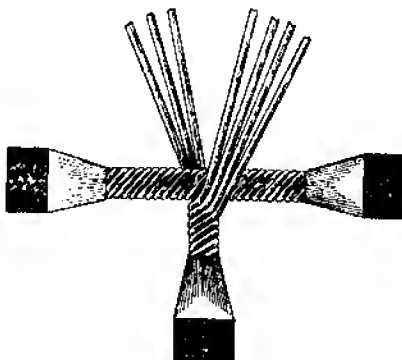


FIG. 189.

Next carefully bare about 3" of the end of the other cable, separate out all the wires, clean each with fine emery cloth, straighten and re-twist them up to about  $\frac{1}{4}$ " from the end of the insulation in a slightly sharper twist than the ordinary cable. Now spread the 7 wires out to form a V, the apex of which is at  $\frac{1}{4}$ " from the insulation, 4 wires being one side and 3 the other.

Next press the other cable into the V as shown in Fig. 189, then, holding the two tightly together, wind *one by one* the 4 wires round in one direction, and the 3 in the opposite direction to, say,  $\frac{3}{4}$ " either side of the centre. Clip off what is not wanted



of each wire, and trim so as to not project outwards, when the joint should be as in Fig. 190.

**To solder.**—Repeat the operation described for joints 7 and 9.

**To insulate.**—Repeat the operation described for joints 7

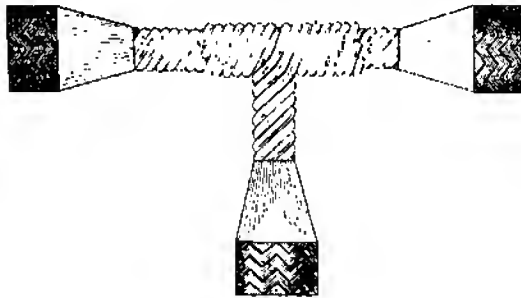


FIG. 190.

and 9, except that when the T is reached, wrap carefully round the angles, down the T and back, stretching the tapes tighter here to allow for the extra lapping this part will receive, then finish off the joint as in 7 and 9 above.

#### TWIST-JOINT No. 11.

**To prepare.**—Carefully bare about  $4\frac{1}{2}$ " of the two ends to be jointed, and separate out the outer layer of 12 wires, clean them with fine emery cloth and straighten. Without unwinding the inner 7 solder them into a solid mass and cut half off in both cables alike. Now re-twist the outer 12 up to the end of the inner 7 with about the same pitch as the ordinary cable, and arrange them to form a cone with the apex at the end of the inner 7. Then pushing the two cones together and interlacing alternately, proceed to finish exactly as in joints 7 and 9.

#### T-JOINT No. 12.

**To prepare.**—Carefully bare about 3" of the cable to be tapped, clean the outside of the stranded core with fine emery cloth, and re-tin it well.

Next carefully bare about  $3\frac{1}{2}$ " of the end of the other cable. Separate out each wire, clean with fine emery cloth, and straighten. Next re-twist both inner and outer sets up to about  $\frac{3}{4}$ " from the insulation with a slightly sharper pitch than the ordinary cable, then *carefully* spread out all the wires in the best possible manner to form a V with 10 one side and 9 the other. Lastly, press the other cable into this V, and finish the joint precisely as in Nos. 8 and 14.

#### TWIST-JOINT No. 13.

**To prepare.**—Carefully bare about  $5\frac{1}{2}$ " of the ends of the cables to be jointed, unwinding the outermost layer of 18 wires, and proceed precisely as in No. 11, except that half the inner 19 must now be cut off after soldering them together.

#### T-JOINT No. 14.

**To prepare.**—Carefully bare about  $4\frac{1}{2}$ " to 5" of the cable to be tapped and about  $5\frac{1}{2}$ " of the end of the other, and proceed exactly as set forth for joint 12, excepting that the V will now have 19 wires on one side and 18 the other. Finish it off as there indicated.

#### TWIST-JOINT No. 15.

**To prepare.**—Carefully cut the lead sheathing away, without in any way nicking the copper core of the cable, for about 4" of the ends of the cables to be jointed. Next slip on to one cable, to some little distance from the joint to be made so as to be out of the way, a lead sleeve consisting of a length of lead piping, a little larger than the size of the lead-covered cable and some 2" longer than the finished joint will be. Then proceed to make the joint and insulate it precisely as in Nos. 7 and 9, taking extra care to get the insulating tapes on tightly and efficiently. Now slip back the loose sleeve over the joint and either carefully "solder" or "solder-wipe" the ends, thus completely sealing in the cable.

**Note.**—If lead piping to the right size is not available, a sleeve may be cut out of lead sheet, bent round the joint and finally sealed along the edge; this, however, does not make so neat a joint as that with the pipe.

## T-JOINT No. 16.

**To prepare.**—Carefully cut away about 4" of the lead sheathing of the cable to be tapped, great pains being taken to avoid nicking the copper core. Next remove about 3½" of the lead sheathing from the end of the other cable and slip over this latter a short sleeve of lead piping slightly larger than the ordinary lead-covered cable, and of sufficient length to cover the insulation of the joint and overlap the end of it. Now make and insulate the joint precisely as described in Nos. 8 and 10 and slip back the small sleeve over the insulation; also cut out a piece of sheet lead to form a sleeve over the rest of the joint, its ends overlapping those of the lead covering on the cable by about 1"; lastly, train and trim these lead coverings to fit closely, and solder or solder-wipe the seams to make a neat water-tight joint.

## TWIST-JOINT No. 17.

Prepare and make the joint precisely as in Nos. 1 and 2, when it will have the appearance shown in Fig. 191, and it may preferably be kept as short as possible in order to facilitate insulating it.

**To insulate.**—Warm up the G.P. covering on either side of the joint, then work and draw down with moistened fingers that on one side half-way over the joint as in Fig. 192, and next that on the other side, giving the form shown in Fig. 193; work the two draw-downs together and sear all the joint with a hot searing iron.

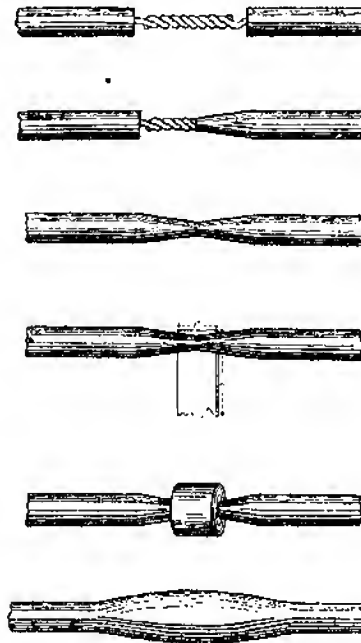
Wrap a strip of G.P. well warmed over a flame round the centre of the draw-down as in Figs. 194 and 195; now work this roll both ways with moistened fingers until it is uniformly distributed over the joint as seen in Fig. 196, finally smoothing all over with a searing iron, and lastly with wetted fingers so as to leave the whole joint quite smooth.

## T-JOINT No. 18.

Prepare and make the joint precisely as in Nos. 3 and 4, keeping its dimensions small.

Insulate in a somewhat similar manner as in No. 17, working the three branch G.P. coverings into each other at the T. Warm

narrow G.P. strip must now be wrapped round the T, first one way and then the other, and drawn down in the three directions so as to leave a clean, smooth, insulated joint.



Figs. 191—196.

## Twist-Joint No. 19.

This joint is made in precisely the same way as No. 11, and is insulated in the same manner, and is shown in Fig. 197.

## SLANTING T-JOINT No. 20.

The cable to be tapped is prepared exactly as in No. 12, the other cable having its inner seven wires soldered together, cut half off and scarfed to the desired angle or slant. The remaining twelve wires are then wound as before in opposite directions, six one way and six the other, round the other cable, giving the joint shown in Fig. 198. The scarf should butt up against the tapped cable and be soldered to it in the final sweating.



FIG. 197.

## STRAIGHT CONCENTRIC-JOINT No. 21.

We will assume that the cable or main is a 37-stranded, lead-covered and armoured one, the gauge being any one of the usual sizes in practice. Treat each of the two ends to be jointed as follows:—Unwrap the outer serving of yarn or hemp for a distance of something like 13 inches from the end, but do not cut it off. Next unwrap the strip armouring for about the same, or a slightly less distance, say 11 or 12 inches, without cutting it off. Then unwrap the inner serving of yarn, which separates the armour and lead sheathing, for some 10 inches, without cutting it off.

Now remove the lead sheathing for about 9 inches altogether.

**Joint in Inner Main.**—Carefully bare the outer conductors for about 7 inches from the end with a sharp knife. Spread out and clean them each with fine emery cloth and straighten, leaving them outspread. Next bare, carefully, the inner conductors for about 5 inches. Spread out and clean each conductor with fine emery cloth and straighten each. Re-twist up the innermost 19 as they were originally, and cut  $\frac{1}{4}$  of this inner 19 strand off. Remove any jagged edges and solder so as to form them into a solid mass.

Each main will now appear as in Fig. 199, except that the unwrapped ends of the yarn and armouring are not shown. Now cut off  $\frac{1}{2}$  of every *alternate* wire immediately surrounding

the inner 19, and bringing the two ends of the cables thus prepared together, so that the inner 19's butt up to each other. Interlace these outer wires so that the respective pairs also butt though alternately on either side of the centre. Then bind this

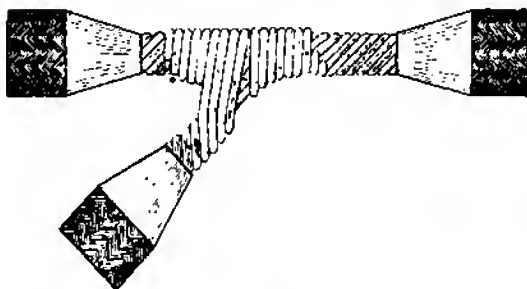


FIG. 198.

first joint of the inner cable with four strips of tinned copper binding wire, each of some ten turns, and the strips equally spaced over the joint, so that the three sets of butts come in between the four strips of binding wire. Lastly, by means of two

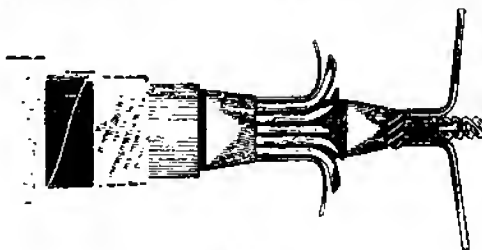


FIG. 199.

ladles, keep pouring melted solder over the joint, catching it in the ladle held underneath and using it over again and again until the joint takes the solder and becomes tinned and soldered into a solid mass. Fine powdered resin must be used as a flux in just sufficient quantity.

When cool enough, taper the end of the first insulating covering, when the joint should then present the form shown in Fig. 200. Now wrap on tightly in the usual way, first pure rubber strip, with the application of rubber solution between layers, and then prepared tape up to a thickness slightly exceeding the other insulation.

**Joint in Outer Main.**—Wrap a sheet or sleeve of copper plate which has been previously cleaned on the outside carefully with emery cloth, and which is of such a thickness as to be comfortably pliable. This sleeve must be the length of the outer conductors, and make one turn or wrap fitting the insulated cable closely. Now cut off half of every *alternate* wire of each outer main and interlace, after cleaning and straightening each as before. Then bend them closely over the sleeve of copper by tinned binding wire in, say, four strips about  $\frac{1}{2}$ " wide, the butts of the conductors being between the pair of strips, either end.

Solder as before with the ladles. The joint now has the appearance shown in Fig. 201.

When cool enough insulate up in the usual way, tapering the ends of the old insulation of the cable beforehand.

**Protections to insulated joint.**—Wrap a piece of sheet lead over the last insulation, so as to form a sleeve of just one complete turn and overlapping the ends of the ordinary lead sheathing of the cable. Then *solder* *scipe* the ends and down the seam so as to make a good water- and air-tight joint.

**Note.**—Any part of the lead may be previously painted if desired so as to prevent the lead solder wiping from taking to that part. Next re-serve the inner yarn as far as it will go over the lead joint, adding more to complete the serving.

Then repeat this operation with the strip armouring, and lastly with the outer yarn, when the joint may finally be well tarred over and is then *complete for laying in*.

Generally speaking, all joints larger than about  $\frac{1}{4}$ " can be more expeditiously and effectively soldered by using flux and pouring molten solder out of one ladle over the joint and catching it in a second and larger ladle underneath. The reason is that by this means the joint can be raised to, and kept at, the proper temperature, which is difficult to obtain with soldering irons.



FIG. 200.

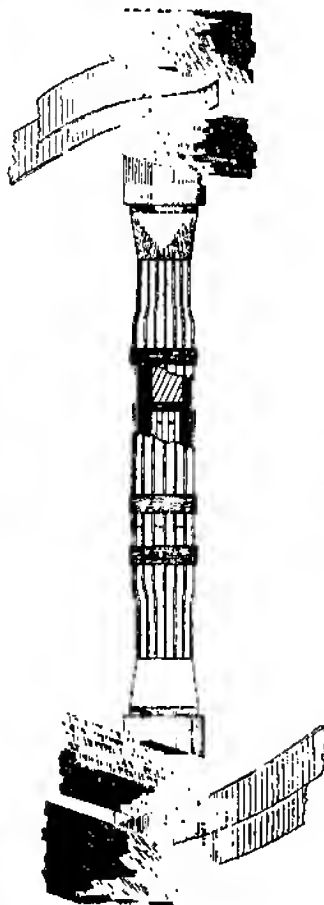


FIG. 201.



# CONTENTS

	PAGE
Curve Plotting . . . . .	1
Calibration and standardization of Ammeters . . . . .	4
Calibration and standardization of Voltmeters . . . . .	16
Complete Test of D.C. and A.C. Ammeters and Voltmeters for all Sources of Error . . . . .	29
Calibration and standardization of Wattmeters . . . . .	34
Calibration and other tests on Electricity Meters . . . . .	43
Efficiency and other Photometric tests on Electric Glow Lamps . . . . .	50
Efficiency and other Photometric tests on Electric Arc Lamps . . . . .	61
Efficiency and other tests on Secondary Cells . . . . .	75
Measurement and comparison of High, Ordinary, and Low Metallic Resistances . . . . .	81
Measurement of the Insulation Resistance of Cables, Cells, Insulators, Machines, and Installations . . . . .	97
Localization of Faults in Electric Light Mains . . . . .	130
Measurement of Rotational Speed by Speed Counter and Watch, and also Stroboscopically . . . . .	134
Determination of the "Characteristics" of Direct Current Dynamoes . . . . .	140
Determination of Field Winding and Speed Conditions for True Compounding of D.C. machines . . . . .	165
Determination of the Characteristics, Regulation, and Efficiency of Alternators . . . . .	168
Determination of Potential around the Commutators of Dynamoes and Motors . . . . .	195
Separation of Losses, Leakage Coefficient, Effect of Air- gap, Faults in Field Coils, Temperature Rise, in Dynamoes and Motors . . . . .	202
Efficiency and regulation of Direct Current Dynamoes . . . . .	219

	PAGE
Efficiency, B.H.P., and regulation of Direct Current Motors	232
Efficiency, B.H.P., and regulation of Alternating Current Induction Motors	260
Efficiency, B.H.P., Regulation, and other Characteristics of A.C. Commutator Motors	299
Efficiency, B.H.P., Regulation, "V" Curves, and other Characteristics of A.C. Synchronous Motors	305
Miscellaneous tests on the Effects of Self-Induction and Capacity in Alternating Current Series and Parallel Circuits	310
Effects of Position of Core, Air Gap, and of one Choke on another in open and closed Magnetic Circuits, etc.	339
Measurement of Magnetic Permeability, Hysteresis, Self- Induction, and Iron Core losses	345
Measurement of the Electrostatic Capacity of Concentric and other Cables	369
Measurement of Power in Single and Polyphase Alternating Current Circuits	379
Efficiency, Regulation, and other tests on Single and Poly- phase Alternating Current Static Transformers	400
Efficiency and Regulation of Electrolytic and Rotary Rectifiers	427
Efficiency and regulation of Continuous and Polyphase Current Rotary Converters	433
Determination of the Periodic E.M.F. and Current Curves of an Alternator or A.C. Circuit by Joubert's Contact Maker and the Duddell Oscillograph	446
Efficiency and Performance of Ventilating Steam- and Gas- Engine Generating "Sets"	462
Jointing in Electric Light Wires and Cables	473
Appendix—Proof of Formule used in the Tests	490
Description of Appliances and Apparatus	504
Tables of Constants, Variables, Copper and Resistances Wires, and Useful Numbers	640
Tables of Logarithms, Squares, Reciprocals and Doubled Square Roots of Numbers	657
Index	667

# INDEX

Test No.	A	Page
	Absolute C.G.S. Units, Table relating Practical and	643
	Absorption Brake for measuring Horse-power of Motors	234 & 621
	----- Dynamometer	633
	----- Dynamometer, Cradle	621
23	----- of Light by Shades and Globes, Measurement of the	68
	Air at different Temperatures and Pressures, Table of Densities of Dry	850
	----- Condenser, Kelvin's	616
119	----- Gap in Closed Magnetic Circuit on Impedance, Reactance, Self-Induction, Current and Power, Effect of Length of	341
79	----- Gaps in a Dynamo, Effect on the Magnetic Characteristic of the Alternating and D.C. Electro-Motors, General Remarks on the Testing of	211
127	----- Current, Absolute Measurement of Self-Induction by Rowland's Method and	232
	----- Current Circuits, Effects of Variation of Frequency in	362
117	----- Current Circuits, Load and Wattless Currents in Inductive	310
109	----- Current Circuits, Measurement of Power Factor in	336
185	----- Current Circuits, Measurement of Power in 3-phase	316
	----- Current Circuits, Measurement of Power in 2-phase	388 & 395
133	----- Current Circuits, Power absorbed in, by 1-Voltmeter method	393 & 395
134	----- Current Circuits, Power (by 3-Ammeter Method) in	379
	----- Current Circuits, Relation of Supply Factors to Constants of	383
106	----- Current Commutator Motors, Efficiency and B.H.P. of Single-phase	310
128	----- Current, comparison of two Self-Inductions by Rowland's Method and	299
160	----- Current Electro-Motors, Efficiency and B.H.P. of Multi-phase	365
99	----- Current Electro-Motors, Efficiency and B.H.P. of Single-phase	272
124	----- Current Frequency, Method of Separating Iron Losses	289
	----- Current, General Remarks on Measurement of Self-Induction by Rowland's Method and	362
	----- Current Induction Motors, Testing of Asynchronous	260
126	----- Current, Measurement of Self-Induction by using Single-phase	358
146 & 149	----- Current Rotary Converters, Efficiency of Multi-phase	433 & 439
136-148	----- Current Static Transformers, Measurement of Efficiency of	400-426
106	----- Current Synchronous Motors, Excitation and Armature Current and V Curves of	805
66	----- Alternator (at Constant Excitation), Variation of E.M.F. with Speed in an	163

Test No.		Page
67	Alternator (at Constant Speed), Variation of E.M.F. with Excitation in an . . . . .	169
71	Characteristics for different Power Factors . . . . .	181
70	Determination of the Characteristic of an . . . . .	177
154	Determination of the Periodic E.M.F. and Current Curves of an . . . . .	446
155	Determination of the Periodic E.M.F. and Current Curves of an . . . . .	450
73	Efficiency without loading it up . . . . .	185
	Graphical Deduction of Total Characteristic of an . . . . .	179
	Internal Losses in an . . . . .	185
	Iron Losses by Rotarlution Method . . . . .	189
68	Magnetization Curve on Full Load of an . . . . .	171
67	Magnetization or Open Circuit Characteristic of an . . . . .	169
85	Measurement by Transmission Dynamometer of Efficiency of an . . . . .	230
72	Relation between Exciting and Armature Currents for Constant Voltage on Load . . . . .	184
	Separation of the Internal Losses in an . . . . .	189
69	Short Circuit Characteristic of an . . . . .	173
	"Voltage Drop" in an . . . . .	174
133	Alternators, 3-voltmeter Method of finding the Electrical Power developed by . . . . .	379
74	Efficiency and External Loss Test of a Pair of . . . . .	192
126	Impedance, Reactance, Self-Induction by Alternating Currents . . . . .	358
	Aluminium and Copper, Comparative Table for . . . . .	645
5	Ammeter Calibration by comparison with a Crompton Potentiometer . . . . .	11
2 & 3	Calibration by comparison with a Kelvin Composite Balance . . . . .	7 & 8
4	Calibration by comparison with a Kelvin Centi-Ampere Balance . . . . .	10
1	Calibration by comparison with Standard D'Arsonval Ammeter . . . . .	5
13	Complete Text for Various Sources of Error in Direct and Alternating Current . . . . .	29
6	Standardization by means of a Copper Voltmeter . . . . .	14
	Andor's Planimeter, Direction for using to give area of Indicator Diagram . . . . .	530
	Planimeter, Instructions for working . . . . .	528
77	Analysis of Total Internal Loss of Power in Dynamos and Motors . . . . .	202
	Angle of Lead of the brushes of a Generator . . . . .	197
	Anti-inductive Resistance for use with Kelvin Standard Electric Balance . . . . .	553
	Anti-logarithms, Tables of . . . . .	659
	Arc Lamp Photometer Cradle . . . . .	537
26	Arc Lamps, Determination of the Distribution of Light from . . . . .	47
31	Examination of Alternating Current . . . . .	74
	General Remarks on the Photometry of Electric . . . . .	61
24	Measurement of the Commercial Efficiency of . . . . .	63
25	Measurement of the Net Optical Efficiency of . . . . .	66
30	Relation between Voltage and Current in . . . . .	72
28	Relation between Voltage and Current with consumption of Carbons in . . . . .	70
29	Relation between Voltage and Distance between the Carbons in . . . . .	71

# INDEX

689

Test No.		Page
35	Armature Resistance of Dynamos and Motors, Measurement of the	84
37	Resistance of Dynamos and Motors (Simple Potentiometer Method)	88
	Asynchronous A.C. Induction Motors, General remarks on	260
	Atomic Weights, Table of	544

## B

	Balance, Kelvin Standard Centi-Ampere	516
	— Kelvin Standard Composite	564
132	Ballistic Method of measuring Electrostatic Capacity of Coaxial Cables	377
	Bar Photometer, Trotter's Direct Reading	589
48	Batteries, Measurement of the Insulation Resistance of Storage	127
105	B. H. P. and Efficiency, etc., of Single-phase Commutator Motors	299
107	— and Efficiency, etc., of Synchronous A.C. Motors	309
142	Blakesley's 3-Dynamometer Method of measuring Transformer Efficiency	422
153	Booster, Efficiency of a Motor-Generator or	441
	Brake Absorption Dynamometer or Piony	533
	— Eddy Current	535
	— for measuring H. P. of Motors	234
93	— H. P. and Efficiency of D.C. Compound Wound Electro-Motors	251
89	— H. P. and Efficiency of D.C. Series Wound Electro-Motors	241
92	— H. P. and Efficiency of D.C. Shunt Wound Electro-Motors	218
95	— H. P. and Efficiency of Electro-Motors (Swinburne's Electrical Method)	256
100	— H. P. and Efficiency of Multi-phase A.C. Electro-Motors	272
94	— H. P. and Efficiency of Small Electro-Motors (Cradle Balance Method)	252
99	— H. P. and Efficiency of Single-phase A.C. Electro-Motors	268
90	— H. P. and Efficiency of 500 Volt Direct Current Tram and Railway Motors	245
	— Pulley, Maw's rule for finding the smallest size of a	235
	— Soames' Motor-testing	537
34	Bridge, Measurement of Resistance by the Wheatstone	81
	— Siemens Low Resistance	526
43-4	Bridge-Megger Testing Sets for Insulation and Conductor Resistance, Evershed's	116, 117 & 541
	Britannia Joint in bare overhead wires	478
83	Brush Position on Commutator of Motor Variation of Voltage, Current, and Speed with	239
	Bunsen's Photometer Screen	592

## C

	Cables and Wires, General Remarks on Electrostatic Capacity of	369
41	— and Wires, &c., Insulation Resistance of, by Direct Deflection	99
43	— and Wires, &c., Insulation Resistance of, by Evershed Set	118
42	— and Wires, &c., Insulation Resistance of, by Silvertown Set	105
260	— Detailed Instructions for Jointing Electric Light	474
	— General Observations on Jointing Electric Light	473
	— in Testing Insulation Resistance, Preparation of the Ends of	99

Test No.		Page
191	Cables, Measurement by Kelvin Voltmeter Method of Electrostatic Capacity of	874
35	— Measurement of the Resistance of Electric Light	84
12	Calibration of a High Tension Alternating Current Voltmeter	75
17	— of a High Tension Wattmeter by application of Ohm's Law	41
11	— of a Voltmeter by comparison with a Crompton Potentiometer	33
10	— of a Voltmeter by comparison with a Kelvin Centi-Ampere Balance	22
9	— of a Voltmeter by comparison with a Kelvin Composite Balance	21
8	— of a Voltmeter by comparison with a Standard D'Arsonval Voltmeter	18
14	— of a Wattmeter by comparison with a Kelvin Composite Balance	34
15	— of a Wattmeter by comparison with a Standard Ammeter and Voltmeter	37
16	— of a Wattmeter with Alternating Currents (3-Voltmeter Method)	38
4	— of an Ammeter by comparison with a Kelvin Centi-Ampere Balance	10
2	— of an Ammeter by comparison with a Kelvin Composite Balance	7
3	— of an Ammeter by comparison with a Kelvin Composite Balance	8
1	— of an Ammeter by comparison with a Standard D'Arsonval Ammeter	5
5	— of an Ammeter by means of a Crompton Potentiometer	11
18	— of an Electricity Meter	49
7	— of Direct Current Voltmeters (Poggendorf's Method)	16
	— of Electrical Measuring Instruments, General Remarks on the	4
51	— of Speed Indicators	134
21	Candle Power and Efficiency of Electric Glow Lamps, Measurement of the	50
	— Power (mean spherical) of an Electric Arc Lamp	70
	— Power (mean spherical) of an Electric Glow Lamp	50
22	— Power, Variation of, with direction around an Electric Glow Lamp	55
113	Capacity and Ohmic Resistance in Circuits, Effect of Frequency with	328
33	— and Efficiency of Secondary Cells, Measurement of the Storage	76
	— and Efficiency of Secondary Cells, Ways of Denoting	78
	— Current of a Cable or Main	573
	— of Cables (Kelvin Voltmeter Method), Proof of Formula in	600
	— of Cables (Magnetometer Method), Proof of Formula in	601
132	— of Concentric Cables (ballistically), the Electrostatic	377
	— of Concentric Cables, Formula expressing the	371
180	— of Concentric or Ordinary Cables and Condensers (A.C. Method), Electrostatic	372
	— of Electrical Wires and Cables, Measurement of the Electrostatic	372-9
181	— of Short Cables (Kelvin "Voltmeter Method"), the Electrostatic	374
	Carbon Rheostat, Adjustable	698
	Carhart-Clark Standard Cell, Temperature coefficient of the	17 & 643

# INDEX

671

Test No.		Page
	Colla, Proof of Formula giving Internal Resistance of Secondary Coul-Ampere Balance, Constants (when used as a Voltmeter) of Kelvin's . . . . .	491 550 546
62	"Characteristic" of a Compound Wound Dynamo (Long Shunt), Determination of the . . . . .	160
	— of a Compound Wound Dynamo (Long Shunt), Graphical deduction of Total . . . . .	162
63	— of a Compound Wound Dynamo (Short Shunt), Determina- tion of the . . . . .	163
	— of a Compound Wound Dynamo (Short Shunt), Graphical deduction of Total . . . . .	164
79	— of a Dynamo with varying Air Gaps, Magnetic . . . . .	211
147	— of a Rotary Converter, "No Load" (open circuit) . . . . .	438
60	— of a Shunt Wound Dynamo, Determination of the . . . . .	165
	— of a Shunt Wound Dynamo, Graphical Deduction of Total . . . . .	167
70	— of an Alternating Current Generator, Determination of . . . . .	177
71	— of an Alternator, for Different Power Factors . . . . .	181
	— of an Alternator, Graphical Deduction of the Total . . . . .	179
69	— of an Alternator, The Short Circuit . . . . .	173
	— of Magneto Dynamo, Graphical Determination of Total . . . . .	145
66	— of Separately Excited Dynamo, Determination of the . . . . .	147
58	— of Series Wound Dynamo, Determination of the External . . . . .	150
	— of Series Wound Dynamo, Graphical Deduction of Total . . . . .	152
136	— of Static Transformers, Magnetization on Open Circuit . . . . .	401
148 & 149	— and Efficiency of Rotary Converters (Run from D.C. and A.C. Sides . . . . .	433 & 439
56	— or Curves of Magnetization of Separately Excited Dynamo, Internal . . . . .	143
59	— or Curves of Magnetization of Series Wound Dynamo, Internal . . . . .	155
61	— or Curve of Magnetization of Shunt Wound Dynamo, Internal . . . . .	169
	"Characteristics" of Dynamos, Introductory Remarks on the . . . . .	142
64	— of Magneto Dynamo, Determination of the . . . . .	143
	Chemical Equivalents, Table of . . . . .	444
118	Choker, Variation of Impedance, Reactance and Self-Induction with Position of Movable Core in Solenoidal . . . . .	339
	Circuits (A.C.), General Remarks on Constants and Supply of . . . . .	310
119	— containing Capacity and Self-Induction in Parallel, Variation of Impedance and Phase Relations between Currents in . . . . .	333
	— Effects of Variation of Frequency of Supply in Alternating Current . . . . .	310
113	— having Capacity and Resistance only, Variation of Imped- ance with Capacity, Frequency and Resistance . . . . .	326
112	— having Capacity in Series with Resistance, Numerical and Phase Relation between Voltages and between Voltages and Current . . . . .	328
110	— having Ohmic Resistance and Self-Induction only, Relation between Frequency and Temperature . . . . .	319
115	— having Resistance in Parallel with Self-Induction or Capacity, Numerical and Phase Relation between Main and Branch Outputs . . . . .	332
111	— having Self-Induction and Resistance only, Variation of Impedance with Self-Induction, Frequency and Resistance . . . . .	321

Test No.	Page
114	Circuits having Self-Induction, Capacity and Resistance, Variation of Impedance with Self-Induction, Capacity, Resistance and Frequency . . . . . 323
—	Measurement of Power in 2-Phase . . . . . 393 & 395
135	Measurement of Power in 3-Phase . . . . . 383 & 395
—	Clark Standard Cell, Preparation of the . . . . . 504
—	Clark's Standard Cell, relation between E.M.F. and temperature of . . . . . 17 & 643
78	Coefficient of Magnetic Leakage in Machines (Ballistic Method) . . . . . 207
—	of Magnetic Dispersion in Induction Motors . . . . . 233
128	Coefficients of Self-Induction (by Alternating Currents), Comparison of two . . . . . 365
24	Commercial Efficiency of an Arc Lamp, Measurement of the . . . . . 63
73	Efficiency of an Alternator . . . . . 135
85	Efficiency of a Generator, Determination by Transmission Dynamometer . . . . . 230
84	or Net Efficiency of D.C. Dynamos (Kapp's Electrical Method) . . . . . 228
105	Commutator Motors, Efficiency and B.H.P. of Single Phase . . . . . 299
—	Composite Balance, Constants for Kelvin's . . . . . 556-8
—	Balance, Kelvin's . . . . . 554
84	Compounding a Dynamo, Determination of Field Magnet Windings for truly . . . . . 165
85	a Dynamo, Determination of Speed and E.M.F. for truly . . . . . 167
62	Compound Wound Dynamo (Long Shunt), Determination of the Characteristic of a . . . . . 180
—	Wound Dynamo (Long Shunt), Graphical deduction of Total Characteristic of a . . . . . 162
53	Wound Dynamo, Relation between Speed and E.M.F. in . . . . . 140
63	Wound Dynamo (Short Shunt), Determination of the Characteristic of a . . . . . 163
—	Wound Dynamo (Short Shunt), Graphical deduction of Total Characteristic of a . . . . . 164
93	Wound Electro-Motors, Efficiency and B.H.P. of Direct Current . . . . . 251
132	Concentric Cables, Measurement ballistically of Electrostatic Capacity of . . . . . 377
—	Main, Straight Joint in a . . . . . 496
130	or Ordinary Cables and Condensers (A.C. Method), Electrostatic Capacity of . . . . . 372
—	Condensers, Kelvin's Air . . . . . 510
—	Conductivity Test of Copper Wire by Siemens' Low Resistance Bridge . . . . . 527
38 & 44	Conductor Resistance, Measurement by a Portable Testing Set of Metallic . . . . . 90 & 117
4	"Constant" of an Ammeter, Determination of, by a Copper Voltmeter . . . . . 14
—	Constants, useful . . . . . 654
—	Contact Maker, Revolving . . . . . 619
—	Continuous and A.C. Electro-Motors, General Remarks on the Testing of . . . . . 232
—	Conversion in Multi-phase Rotaries, Voltage ratio of . . . . . 437 & 439
—	ratio of A.C. Static Transformers . . . . . 402
146 & 149	Converters, Efficiency of Multi-phase Rotatory . . . . . 433 & 435
147	"No Load" characteristic of Rotary . . . . . 438
148-152	Other tests on Rotary . . . . . 439-443



# INDEX

673

Test No.		Page
	Converters, Synchronising Rotary . . . . .	441
	Copper and Aluminium, Comparative Table for . . . . .	615
	— Conductors, Standards for . . . . .	640-3
	— Electro-Chemical Equivalent of . . . . .	11
137	— Losses in Transformer (Short Circuit Test) . . . . .	407
	— Voltmeters, Directions as to the use and arrangement of . . . . .	14
	Cradle, Absorption Dynamometer . . . . .	621
	— Arc Lamp Photometer . . . . .	687
64	— Balance, Method of finding the Efficiency and B.H.P. of D.C. or A.C. Motors . . . . .	252
	Critical Resistance at a given Speed for a Series Wound Dynamo . . . . .	154
	— Resistance at a given Speed for a Shunt Wound Dynamo . . . . .	159
	Commutator of a Dynamo, General Remarks on, and Thompson's Method of finding the Distribution of Potential round the . . . . .	196
75	— of a Dynamo, Morday's Method of finding the Distribution of Potential round the . . . . .	199
76	— of a Dynamo, Morday Swinburne Method, ditto . . . . .	201
80	Coils, Localisation of Faults in Magnetizing . . . . .	213
	Crompton D'Arsonval Galvanometer . . . . .	569
	Crompton's Potentiometer . . . . .	510
154	Current and E.M.F. Curves of an Alternator, the Periodic . . . . .	446
	— in Circuits having Ohmic Resistance and Self-Induction only, Relation of Frequency and . . . . .	310
	Curve Plotting . . . . .	1
	— Plotting, Notation for points in . . . . .	3
	— Tracer, Kwing's Magnetic . . . . .	609
	Curves of Electrical Horse-power Developed . . . . .	147
	— Polar . . . . .	56

## D

	D'Arsonval Galvanometer, Crompton . . . . .	569
	Densities of Dry Air at different Temperatures and Pressures, Table of . . . . .	650
78	Distribution of Waste Field in Dynamos, Determination of the Relative . . . . .	207
25	— of Light from an Electric Arc Lamp . . . . .	67
22	— of Light from an Electric Glow Lamp . . . . .	55
	— of Potential round the Commutator of a Dynamo, General remarks on, and Thompson's Method . . . . .	195
76	— of Potential round the Commutator of a Dynamo (Morday's Method) . . . . .	199
76	— of Potential round the Commutator of a Dynamo (Morday-Swinburne) . . . . .	201
	Dimple Square Roots for Kelvin Balances, Table of . . . . .	685
156	Duddell Oscillograph, "Wave-forms" by the . . . . .	451
61	Dynamo, Determination of Separate Field Magnet Winding for Truly Compounding . . . . .	105
65	— Determination of Speed and E.M.F. which produces a True Compounding . . . . .	167
62	— Determination of the Characteristic of a Compound Wound (Long Shunt) . . . . .	160
63	— Determination of the Characteristic of a Compound Wound (Short Shunt) . . . . .	163
60	— Determination of the Characteristic of a Shunt Wound . . . . .	155

X X

Test No.		Page
	Dynamo, Determination of the Critical Resistance (at given speed) for a Series . . . . .	154
59	— Determination of the Curve of Magnetization of a Series Wound . . . . .	155
61	— Determination of the Curve of Magnetization of a Shunt Wound . . . . .	159
58	— Determination of the External Characteristic of a Series . . . . .	150
	— Determination of the Total Characteristic of a Compound Wound (Long Shunt) . . . . .	162
	— Determination of the Total Characteristic of a Compound Wound (Short Shunt) . . . . .	161
	— Determination of Total Characteristic of Series Wound . . . . .	153
	— Determination of the Total Characteristic of a Shunt Wound . . . . .	157
	— Dispersion Coefficient in Induction Motors . . . . .	238
75	— Mondy's Method of finding the distribution of Potential round the Commutator of a . . . . .	199
76	— Morley-Swinburne Method, ditto . . . . .	201
	— Thompson's Method of finding the Distribution of Potential round the Commutator of a . . . . .	195
79	— with varying Air Gaps, Magnetic Characteristics of . . . . .	211
	— Dynamometer, Absorption . . . . .	633
	— Cradle Absorption . . . . .	621
85	— Measurement of Efficiency of a Generator by Transmission . . . . .	230
	— Measuring Instruments, Parr's Direct-reading . . . . .	572
	— Siemens Electro- . . . . .	577
	— Siemens Horse-power Transmission . . . . .	623
	— Spring Transmission . . . . .	626
	— Wattmeter, Siemens . . . . .	580
77	Dynamos and Motors, Analysis of Internal Loss of Power in . . . . .	202
43 & 49	— Measurement of the Insulation Resistance of . . . . .	113 & 129
54	— Determination of the "Characteristic" of Magneto . . . . .	143
55	— Determination of the "Characteristic" of separately excited . . . . .	147
83	— Efficiency by Hopkinson's Electrical Method of Direct Current . . . . .	223
84	— Efficiency by Kapp's Electrical Method of Direct Current . . . . .	226
82	— Efficiency by Swinburne's Electrical Method of Direct Current . . . . .	219
56	— Internal Characteristic or Curve of Magnetization of separately excited . . . . .	148
	— Introductory Remarks on the "Characteristics" of . . . . .	142
57	— Relation between External and Exciting Currents of separately excited . . . . .	149
53	— Relation between Speed and E.M.F. in Direct Current . . . . .	140
<b>X</b>		
	Eddy Current Absorption Dynamometer Brake . . . . .	535
123	— Currents in Magnetic Material, Measurement of . . . . .	348 & 352
93	Efficiency and B.H.P. of D.C. Compound Wound Electro-Motors . . . . .	251
89	— and B.H.P. of D.C. Series Wound Electro-Motors . . . . .	241
92	— and B.H.P. of D.C. Shunt Wound Electro-Motors . . . . .	248
95	— and B.H.P. of Electro-Motors (Swinburne's Electrical Method) . . . . .	255
90	— and B.H.P. of 500 Volt Direct Current Tram and Railway Motors . . . . .	245
94	— and B.H.P. of small Electro-Motors (Cradle Balance Method) . . . . .	252

# INDEX

875

Test No.		Page
100	Efficiency and B.H.P. of Multi-phase A.C. Electro-Motors . . .	272
99	— and B.H.P. of Single-phase A.C. Electro-Motors . . .	269
24	— and C.P. of Electric Arc Lamps, Measurement of the Commercial . . .	63
25	— and C.P. of Electric Arc Lamps, Measurement of the Net Optical . . .	66
21	— and C.P. of Electric Glow Lamps, Measurement of the . . .	60
74	— and Internal Loss Test of a Pair of Alternators . . .	182
33	— and Storage Capacity of Secondary Cells, Measurement of the . . .	76
	— and Storage Capacity of Secondary Cells, Ways of representing the . . .	73
105	— I. H.P. &c., of Single-phase Commutator Motors . . .	299
107	— B.H.P. &c., of Synchronous A.C. Motors . . .	309
155	— of a Recoter or Motor Generator Set . . .	444
158	— of a Gas-Engine Dynamo Generating Set, the Commercial . . .	405
86	— of a Generator, Measurement by Transmission Dynamometer of the . . .	220
144	— of a Nodon Valve Rectifier . . .	427
145	— of a Rotary Rectifier . . .	431
159	— of a Steam-Engine Dynamo Generating Set, the Commercial . . .	468
72	— of an Alternator without loading it up . . .	185
167	— of an Electro-Motor-Fan Set . . .	402
96	— of D.C. Electro-Motors (Eadie's Electrical Method) . . .	258
83	— of Direct-Current Dynamos (Hopkinson's Electrical Method) . . .	223
84	— of Direct-Current Dynamos (Kapp's Electrical Method) . . .	226
82	— of Direct-Current Dynamos (Swinburne's Electrical Method) . . .	219
	— of Dynamos (Hopkinson's Method), Proof of Formula for the . . .	437
101	— of Induction Motor (Heyland Method) . . .	277
102	— of Induction Motor (Sumpner-Weeks method) . . .	238
143 & 149	— of Multi-phase A.C. Rotary Converters . . .	433 & 439
141	— of Multi-phase A.C. Static Transformers . . .	424
139-142	— of Single-phase A.C. Static Transformers . . .	412-424
142	— of Single-phase A.C. Static Transformers (Blakesley's Dynamometer Method) . . .	422
140	— of Single-phase A.C. Static Transformers (by Double Conversion) . . .	414
139	— of Single-phase A.C. Static Transformers (by Single Conversion) . . .	412
141	— of Single-phase A.C. Static Transformers (by Sumpner's Method) . . .	417
	— of Transformers (Blakesley's Method), Proof of Formula for the . . .	502
103	— Slip, Torque, Load, &c., in Induction Motor with Variable Rotor Circuit Resistance, Relation between . . .	294
13	Electricity Meter, Calibration of an . . .	48
19	— Motor, Complete Test of an . . .	45
	Electro-Chemical Equivalents of Copper for various current densities, Table of . . .	41
	— Equivalents, Table of . . .	644
	Electro-Dynamometer, Siemens . . .	577
144	Electrolytic Rectifier, Efficiency of a Nodon Valve . . .	427
94	Electro-Motors, Efficiency and B.H.P. (by Cradle Balance Method) of small . . .	282
95	— Efficiency and B.H.P. (by Swinburne's Electrical Method) of . . .	255

X X 2

Test No.		Page
93	Electro-Motors, Efficiency and B.H.P. of D.C. Compound Wound	231
88	— Efficiency and B.H.P. of D.C. Series Wound	241
92	— Efficiency and B.H.P. of D.C. Shunt Wound	248
100	— Efficiency and B.H.P. of Multi-phase A.C.	272
99	— Efficiency and B.H.P. of Single-phase A.C.	283
96	— (Poulo's Electrical Method), Efficiency of D.C.	258
	— General remarks on the Testing of continuous and A.C.	232
122	Electrostatic Capacity of Concentric Cables by Standard Magneto Inductor Method	377
180	— Capacity of Concentric or Ordinary Cables and Condensers by the Alternating Current Method	372,
	— Capacity of Electric Wires and Cables, General Notes on the	269
131	— Capacity of Short Cables by Kelvin Multicellular Voltmeter Method	374
	— Voltmeters	362
	— Voltmeters, Kelvin's Multicellular	593
155	E.M.F. and Current Curves of an Alternator (Ballistically), the Periodic	450
154	— and Current Curves of an Alternator (Electrostatically), the Periodic	440
65	— and Speed at which a Dynamo truly Compounds, Determination of	167
53	— and Speed in Direct Current Dynamos, Relation between	140
	— and Temperature of Clark's Weston Cadmium and Carlhart-Clark's Standard Cells, Table giving	613
	— of an Alternator, Algebraical Relation expressing the Total	170
	— of an Armature Coil at different positions (Thompson's Method), Investigation of	198
	— of Armature Coils, Thompson's Method of Measuring the	198
07	— with Excitation (at constant speed) in Alternators, Variation of	169
06	— with Speed (at constant excitation) in Alternators, Variation of	168
	Errors in Ammeters and Voltmeters, Enumeration of	29
	Eureka Resistance Material, Table for	548
	Evershed Bridge-Megger Constant Pressure Generator for	544
	— Bridge-Megger Index, Adjuster for	546
	— Bridge-Megger Insulation Testing Set, Description of the	541
	— Megger Insulation Testing Set, Description of the	539
	— Portable Testing Sets, Description of the	539
125	Ewing's Hysteresis Tester, Measurement of Magnetic Hysteresis by	356
	— Magnetic Curve Tracer	609
07	Excitation with Speed of D.C. Motors, Variation of (for Constant Voltage)	238
58	External Characteristic of Series Dynamo, Determination of the	160

## F

	Factor in Induction Motors, Leakage	228
109	— in A.C. Circuits, Measurement of Power	316
157	Fan Set, Efficiency of an Electro-Motor	462
50	Faults in Electric Mains, Localization of	180
80	Faults in Magnetizing Coils, Localization of	213

# INDEX

677

Test No.		Page
64	Field Magnet Windings for Truly Compounding a Dynamo, Determination of	166
•	Frequency, Slip and Speed, Measurement by Stroboscopic Method	282
111	— and Current, Power, Impedance, and Angle of Lag in Circuits having Ohmic Resistance and Self-Induction only, Relation between	321
110	— and Temperature in Circuits having Ohmic Resistance and Self-Induction only, Relation between	319
113	— on Circuits having Capacity and Ohmic Resistance, Effect of	326
114	— on Circuits having Self-Induction, Capacity, and Ohmic Resistance, Effect of	328
•	— of the Supply in A.C. Circuits, Effects of Variation of the	319
	True Table for Different Diameters and Currents	654

## G

	Galvanometer, Crompton D'Arsonval	549
	Galvanometers, Deviation of deflection from direct proportionality in reflecting	490
	— Sensitive Portable	571
168	Gas-Engine Generating Set, the Commercial Efficiency of	405
	Gauges, Weights, Resistances and Sections, Table giving relation of different metals of	653
	— Comparison of different Wire	650
	Gearing of Engine Indicators	469
	Generator, the Eversheld Bridge-Megger Constant Pressure	514
21	Glow Lamps, Measurement of the Efficiency and C.P. of Electric	50
22	— Variation of C.P. with direction around an Electric	55
	Guard-wire in Tests on the Insulation Resistance of Cables, Price's	100

## H

• 101	Hopland Diagram, Experimental and Graphical Deduction of	277
74	Hopkinson Principles for Testing a Pair of Alternators	192
83	Hopkinson's Electrical Method of Measuring Efficiency of D.C. Dynamos	223
	— Method of Measuring Dynamo Efficiency, Proof of Formula	497
122	— Permeameter, Measurement of Magnetic Permeability by	347
102	Hopkinson-Stumpner Method of Testing Induction Motors	288
	Horse-power Curves	147
	— Transmission Dynamometer, Siemens	623
	Houssman's Method of Separating the Internal Losses in a Dynamo or Motor	204
126	Hysteresis by Kwing's Hysteresis Tester, Measurement of Magnetic	356
123	— in Magnetic Material (Single-phase A.C.s), Measurement of Magnetic	348
	— Test, Preparation of Iron samples for	350
	Horizontal Candle Power, Mean	56

I. H. P. of a Compound or Triple-Expansion Engine, Determination of the	473
Illumination Photometer, Trotter's	590

Test No.	Page
116	Impedance and Phase Relations between Currents in Circuits having Capacity and Self-Ind. in Parallel, Variation of . . . 833
118	Resistance and Self-Ind. with Position of Movable Core in Solenoidal Choker . . . 839
126	Resistance and Self-Ind. of Alternators, Motors, Transformers, &c. by Alternating Currents . . . 858
119	Resistance, Self-Ind., Current and Power, Effect of Length of Air Gap in a Closed Magnetic Circuit on . . . 841
118	with Capacity, Frequency, and Resistance in Circuits having Capacity and Resistance only, Variation of . . . 828
114	with Self-Ind., Capacity, and Resistance in Circuits having Self-Ind., Capacity, and Resistance, Variation of . . . 398
111	with Self-Ind., Frequency and Resistance in Circuits having Self-Ind. and Resistance only, Variation of . . . 321
	Indicator Diagram, Determination of the I.H.F. from the Diagram, Form and Explanation of an . . . 471
51	Indicators, Calibration of Speed . . . 134
	Gearing of Engine . . . 489
	Table of Springs for Thompson's Steam-Engine . . . 534
	Thompson's Steam-Engine . . . 531
101	Induction Motor, Complete Test without loading it up . . . 277
102	Motor, Complete Test by Sumner-Weekes method . . . 288
104	Motor, Relation between Starting Torque, Current, Voltage, and the Rotor Circuit resistance of an . . . 296
100	Motors, Efficiency and H. P. of Polyphase . . . 272
99	Motors, Efficiency and H. P. of Single Phase . . . 269
97	Motors, No-Load Open-circuit Test on . . . 284
98	Motors, No-Load Short-circuit Test of . . . 267
	Motors, Ratio of Transformation in . . . 265
	Motors, Testing of Asynchronous A.C. . . . 260
103	Motors with variable Rotor Circuit Resistance, Relation between Efficiency, Slip, Torque, Load, &c., in . . . 294
117	Inductive A.C. Circuits, Determination of Load and Wattless Currents in . . . 328
120	Effects due to the relative Positions of 2 Coiled Circuits, Investigation of Mutual . . . 348
	Drop of an Alternator with Load and Power Factor . . . 174
	Retardation . . . 370
106	Inductiveness of a Circuit, Determination of the . . . 314
	Instruments, General Remarks on the Calibration of Electrical Measuring . . . 4
	Insulation Resistance, Actual Values for given Voltage and Number of Lampe . . . 112
	Resistance by Direct Deflection Method, Proof of Formula for . . . 493
	Resistance, General Remarks on . . . 98 & 109
42	Resistance, Measurement by the Silvertown Portable Testing Set . . . 105
41	Resistance of Cables, Measurement by Direct Deflection Method . . . 99
40	Resistance of Dynamos and Motors, Measurement of the . . . 129
	Resistance of Dynamos and Motors, Proof of Formula for . . . 496
	Resistance of Electrical Cables and Installations . . . 98 & 109
47	Resistance of Faulty Telegraph Insulators . . . 128
43	Resistance of Installations, etc., by Evershed's Portable Megger and Bridge-Megger Testing Sets . . . 113-116 & 589

# INDEX

679

Test No.		Page
45	Insulation Resistance of Installations, etc., while working	119
46	Resistance of Installations, etc., while working	121
•	Resistance of Installations while working, Proof of Formula for	494
48	Resistance of Storage Batteries, Measurement of the	127
—	Resistance of Storage Batteries, Proof of Formula for	496
—	Resistance with Testing Voltage, Variation of	113
—	Insulators for Postal and other Telegraph Lines	123
56	Internal Characteristics of Separately Excited Dynamos	148
59	Characteristic of Series Wound Dynamos	133
61	Characteristic of Shunt Wound Dynamos	159
74	Loss and Efficiency Test of a Pair of Alternators	192
77	Loss of Power in Dynamos and Motors, Analysis of the	202
—	Losses in an Alternator	186
—	Losses in an Alternator, Separation of the	189
82	Resistance of Secondary Cells, Measurement of the	75
—	Resistance of Secondary Cells, Proof of Formula giving	491
—	Iron Losses in Alternators by Retardation Method	190
124	Losses, Separation of, by A.C. Frequency Method	352

## J

	Joining Electric Light Cables and Mains, Course in	475
160	Electric Light Cables, Detailed Instructions for	474
—	Electric Light Cables, General Observations on	473
—	Jolly's Photometer Screen	593

## K

84	Kapp's Electrical Method of Measuring Efficiency of D.C. Dynamos	226
—	Method of Separating the Internal Losses in Dynamos and Motors	203
•	Klein Air Condenser	616
—	Magneto-static Current Meter	568
—	Multicellular Electrostatic Voltmeter	563
—	Standard Balances, Adjustment of the	560
—	Standard Centi-Ampere Balance	546
—	Standard Centi-Ampere Balance, Anti-Inductive Resistances for	553
—	Standard Centi-Ampere Balance, Constants when used as a Voltmeter	560
—	Standard Composite Balance	564
—	Standard Composite Balance, Constants for	568-9
131	"Voltmeter Method" of finding Electrostatic Capacity of Short Cables	374
•	Key, Highly insulated 2-way spring tapping	630
—	Pohl's change-over commutator	633
—	Simple reversing	585
—	Simple 2-way sliding	587

## L

121	Log in Circuits having Ohmic Resistance and Self-Induction only, Effect of Frequency on Angle of	321
—	Lagging and Leading Currents in a Circuit, the Production of	181

Test No.		Page
	Lamp-box Resistance, Incandescent . . . . .	599
129	Laws of Combination of Self-Inductions in Series and Parallel . . . . .	599
	Lead-covered Cables, Twist-Joint in . . . . .	483
	— Cables, T-Joint in . . . . .	484
	Lead of Brushes in a Dynamo, Angle of . . . . .	197
78	Leakage Coefficient " $\mu$ " in Dynamos, Determination of the Magnetic . . . . .	207
	— Factor in Induction Motors . . . . .	288
	Liquid Rheostat, Three-phase . . . . .	607
	Liquids, Table of Specific Resistances of . . . . .	645
117	Load and Wattless Currents in an Inductive A.C. Circuit, Determination of the . . . . .	336
100	Load-Efficiency Test of an Induction Motor . . . . .	272
50	Localization of Faults in Electric Mains . . . . .	130
80	— of Faults in Magnetizing Coils . . . . .	213
	Low Resistance, Approximate Test for a very . . . . .	524
	— Resistance Bridge, Siemens form . . . . .	525
	— Resistance Fixed Standard . . . . .	604
	— Resistance Measurer, Description of a . . . . .	621
40	— Resistance, Measurement by "Nahler" Measurer . . . . .	97 & 321
37	— Resistance, Measurement by Simple Potentiometer Method . . . . .	88
36	— Resistance, Measurement by Voltmeter and Ammeter Method . . . . .	83
35	— Resistance (Potential Difference Method), Measurement of . . . . .	84
	— Resistance (Potential Difference Method), Solution of In- ferences for . . . . .	492
	Logarithms, Tables of . . . . .	687
124	Losses in Iron, Separation of, by A.C. Frequency Method . . . . .	352
137	— in Transformers (by Short Circuit Test), Copper . . . . .	407
	— in Transformers on Open Circuit (constant) . . . . .	403
	Lummer Brodhun Photometer Screen, Principle of . . . . .	593

## M

81	Magnet Coils, Rise of Temperature and Increase of Resistance of . . . . .	216
79	Magnetic Characteristic of a Dynamo with Varying Air Gaps . . . . .	211
	— Curve Tracer, Ewing's . . . . .	600
	— Dispersion in Induction Motors, Coefficient of . . . . .	288
125	— Hysteresis, by Ewing's Hysteresis Tester, Measurement of . . . . .	350
123	— Hysteresis in Magnetic Material (Single-phase A.C.s), Measurement of . . . . .	348
78	— Leakage Coefficient " $\mu$ " in Dynamos, Determination (by Ballistic Method) of the . . . . .	207
123-4	— Material, Measurement of Hysteresis (Single-phase A.C.s), in samples of . . . . .	348-352
122	— Permeability, by Hopkinson's Permeameter, Measurement of . . . . .	347
121	— Permeability by the Permeameter, Measurement of . . . . .	345
	— Slip in A.C. Motors . . . . .	280-2
67	Magnetization Characteristic of an Alternator . . . . .	169
68	— Curve of an Alternator on Full Load . . . . .	171
66	— Curve of Separately Excited Dynamo . . . . .	148
59	— Curve of Series Wound Dynamo . . . . .	155
61	— Curve of Shunt Wound Dynamo . . . . .	159
186	— Curve or "Open Circuit" Characteristic of Static Trans- formers . . . . .	404



Test No.		Page
147	Magnetization Curves or "Open Circuit" Characteristic of Rotary Converter . . . . .	438
89	*Magnetizing Coils, Localization of Faults in . . . . .	213
54	Magneto Dynamo, Determination of the Characteristic of a . . . . .	143
	— Dynamo, Graphical Deduction of Total Characteristic of a . . . . .	145
	Magneto-static Current Motor, Kelvin's adjustable . . . . .	558
	Manganin Resistance Material, Table giving Rise of Temperature for Different Currents in . . . . .	649
	Maw's Rule for finding the smallest size of a Brake Pulley . . . . .	235
	Mean-spherical and Horizontal Candle Power . . . . .	56
	Measuring Instruments, Parr's Direct-Reading Dynamometer . . . . .	572
	"Megger" Insulation Testing Set, Evered's . . . . .	134 & 539
18	Meter, Calibration of an Electricity . . . . .	43
19	— Complete Test of an Electricity . . . . .	45
	Michsen Screen Photometric Standard of Light . . . . .	595
75	Monkey's Method of finding the Distribution of Potential round a Dynamo Commutator . . . . .	199
	— Method of Separating the Internal Losses in Motors and Dynamos . . . . .	203
76	Monkey-Swinburne Method of finding the Distribution of Potential round a Dynamo Commutator . . . . .	201
153	Motor Generator Set, Efficiency of a Braker or . . . . .	444
	— Testing Brake, Swanes . . . . .	637
86	Motors (at Constant Excitation), Variation of Speed with Voltage on Armature . . . . .	236
88	— (at Constant Excitation), Variation of Speed, Voltage Current with Brush position on Commutator of . . . . .	239
87	— (at Constant Voltage), Variation of Speed with Excitation in D.C. . . . .	238
102	— Complete Test by Swinburn-Wheeler method . . . . .	258
101	— Complete Test without loading up, of Induction . . . . .	277
94	— Efficiency and B.H.P. (by Cradle Balance Method) of small Electro- . . . . .	254
107	— Efficiency and B.H.P., etc., of Synchronous . . . . .	309
93	— Efficiency and B.H.P. of D.C. Compound Wound Electro- . . . . .	251
98	— Efficiency and B.H.P. of D.C. Series Wound Electro- . . . . .	241
92	— Efficiency and B.H.P. of D.C. Shunt Wound Electro- . . . . .	248
90	— Efficiency and B.H.P. of 500-Volt D.C. Series Wound Tramway . . . . .	245
100	— Efficiency and B.H.P. of Multi-phase A.C. Electro- . . . . .	272
109	— Efficiency and B.H.P. of Single-phase A.C. Electro- . . . . .	289
105	— Efficiency and B.H.P. of Single-phase Commutator . . . . .	290
95	— Efficiency and B.H.P. (Swinburn's Electrical Method) of Electro- . . . . .	255
120	— Impedance, Reactance, and Self-Ind. by Alternating Currents . . . . .	559
97	— No-Load "Open Circuit" Test of Induction . . . . .	264
88	— No-Load Short-Circuit Test of Induction . . . . .	267
96	— (Poole's Electrical Method), Efficiency of D.C. Electro- . . . . .	253
	Ratio of Transformation in Induction . . . . .	265
104	Relation between Starting Torque, Current, Voltage, and the Motor Circuit Resistance of an Induction . . . . .	296
91	Relation between Starting Torque and Current in D.C. . . . .	246
106	Relation of Excitation to Armature Current and "V" Curves of Synchronous . . . . .	305

Test No.	Page
— Motors, Testing of Asynchronous A.C. Induction . . . . .	250
— — — Testing of Continuous and A.C. Electro- . . . . .	232
103 — — — With Variable Rotor Circuit Resistance, Relation between . . . . .	294
77 — — — Efficiency, Slip, Torque, Load in an Induction . . . . .	202
49 — — — Motors and Dynamos, Analysis of Internal Loss of Power in . . . . .	129
— — — and Dynamos, Measurement of the Insulation Resistance of . . . . .	563
100 Multicellular Electrostatic Voltmeter, Kelvin's . . . . .	272
146 & 149 — — — A.C. Electro-Motors, Efficiency and B.H.P. of . . . . .	433 & 439
— — — of A.C. Rotatory Converters, Measurement of Efficiency . . . . .	433 & 439
143 — — — A.C. Static Transformers, Measurement of Efficiency of . . . . .	421
59 — — — Murray's Loop Test for faults in Cables . . . . .	130
120 — — — Mutual Inductive Effects due to Relative Positions of 2 Coiled . . . . .	343
— — — Circuits . . . . .	

## N

Nalder Low Resistance Measurer . . . . .	521
— — — Potentiometer . . . . .	507
Nickel-Chrome Resistance Material, Table for . . . . .	647
144 Nodon Valve Rectifier, Efficiency of a . . . . .	427
— — — Non-Inductive Wattmeter, Conditions for, and Object of a . . . . .	404
147 No-Load "Open Circuit" Characteristic of Rotary Converter . . . . .	438
135 — — — "Open Circuit" Characteristic of Static Transformer . . . . .	404
— — — "Open Circuit" Loss in an A.C. Static Transformer . . . . .	402
97 — — — "Open-Circuit" Test on Induction Motor . . . . .	261
98 — — — Short Circuit Test on Induction Motor . . . . .	267
101 — — — Test for Efficiency of Induction Motor (Heyland Method) . . . . .	277
— — — Notation for Points in Curve Plotting . . . . .	3
— — — Numbers and Constants, Useful . . . . .	654

## O

Ohmmeter, Description of the principle of the Evershed . . . . .	539
Open Circuit Losses in Transformers . . . . .	402
67 — — — Circuit Characteristic of an Alternator . . . . .	189
147 — — — Circuit (No Load) Characteristic of Rotary Converter . . . . .	438
97 — — — Circuit (No Load) Test of Induction Motor . . . . .	264
156 Oscillograph, "Wave-forms" by Duddell, . . . . .	451

## P

Parr's Direct-Reading Dynamometer Measuring Instruments . . . . .	672
155 Periodic E.M.F. and Current Curves of an Alternator (Ballistic . . . . .	450
— — — Method) . . . . .	
154 — — — E.M.F. and Current Curves of an Alternator (Electrostatic . . . . .	446
— — — Method) . . . . .	
121 Permeability by the Permeameter, Measurement of Magnetic . . . . .	345
122 — — — by Hopkinson's Permeameter, Measurement of Magnetic . . . . .	347
121 Permeameter, Measurement of Magnetic Permeability by the . . . . .	345
122 — — — Measurement of Magnetic Permeability by Hopkinson's . . . . .	347
— — — This . . . . .	615
112 Phase Relations between Voltages and between Voltage Current . . . . .	828
— — — in Circuits of Capacity in Series with Ohmic Resistance . . . . .	

Test No.		Page
115	Phase Relations between Main and Branch Currents in Circuits having Resistance in Parallel with Self-Ind. or Capacity . . .	332
116	— Relations between the Currents in Circuits having Capacity and Self-Ind. in Parallel, Variation of Impedance and . . .	333
	Photometer Bench, Table giving Ratio of Squares of Distances for a . . .	651
	— Screens (Hansen's, Jolly's and Lummer Brodhun's) . . .	592-5
	— Trotter's Direct-Reading Bar . . .	589
	— Trotter's Illumination . . .	590
	Photometric Cradle, Arc Lamp . . .	587
	— Standard of Light, the Methvan Screen . . .	595
	Photometry of Electric Arc Lamps . . .	61-72
	— of Electric Glow Lamps . . .	59-60
	— Use of Coloured Glass in . . .	58
	Planimeter (Amesler's), Instructions for getting area of Indicator Diagram . . .	530
	— (Amesler's), Instructions for working the . . .	528
	Plotting Curves . . .	1
	Pohl's Commutator . . .	583
	Polar Curves of Distribution of Potential around Commutators . . .	200
	— Curves of Light Distribution from an Electric Arc Lamp . . .	68
	— Curves of Light Distribution from an Electric Glow Lamp . . .	56
	Polyphase A.C. circuits, Measurement of Power in . . .	358-400
96	Ponle's Electrical Method for Efficiency of D.C. Motors . . .	254
	Portable Galvanometer, Sensitive . . .	571
	— Testing Bat (Evershed's), Description of a . . .	532-544
	— Testing Bat (Silvertown), Description of . . .	434
34	Post Office form of Wheatstone Bridge, Measurement of Resistance by the . . .	81
	Potential around a Commutator, Polar Curves of Distribution of . . .	200
35	— Difference Method of Measuring Low Resistances . . .	84
	— Difference Method of Measuring Low Resistances, Proof of Formula in . . .	492
	— round the Commutator of a Dynamo, General Remarks (and Thompson's method) on Distribution of . . .	195
75	— round the Commutator of a Dynamo (Morley's method), Distribution of . . .	199
76	— round the Commutator of a Dynamo (Morley-Swinburne), Distribution of . . .	201
	Potentiometer, Crompton's . . .	510
39	— Method of Comparing Resistances by . . .	94
	— Method of "Setting" Crompton's . . .	514
	— Precaution in using, and Sources of Error in . . .	515
	— The N.C.S. . . .	507
	— Volt Box . . .	621
123	Power absorbed in A.C. Circuits, Three-voltmeter Method of finding the Electrical . . .	379
	— Factor, Measurement of . . .	292, 316, 398
109	— in Alternating Current Circuits, the Apparent . . .	403
	— in Alternating Current Circuits, the True . . .	403
134	— in Alternating Current Circuits, Three-ammeter Method of finding the Electrical . . .	393
	— in 2-phase A.C. Circuits, Measurement of . . .	391 & 396
135	— in 3-phase A.C. Circuits, Measurement of . . .	388 & 395
	— transmitted by Belts . . .	622
	Practical and C.G.S. units, Table showing Relation between . . .	643

Test No.		Page
	Preparation of Iron Samples for Magnetic Hysteresis Test . . .	350
	Price's Guard-wire in Tests on Insulation Resistance of Cables . .	130
	Prony Brakes . . . . .	234 & 683
<b>R</b>		
126	Reactance, Impedance and Self-Ind. of Alternators, Motors, Trans- formers, etc., by Alternating Currents . . . . .	358
118	— Impedance and Self-Ind. with Position of Movable Core in Solenoidal Choker, Variation of . . . . .	359
119	— Impedance, Self-Ind., Current and Power, Effect of Length of Air Gap in a Closed Magnetic Circuit on . . . . .	341
	— of a Cable with Alternating Currents . . . . .	373
	Reciprocals of Numbers, Tables of . . . . .	603
144	Rectifier, Efficiency of a Nodan Valve . . . . .	427
145	— Efficiency of a Rotary . . . . .	431
	Reflecting Galvanometers, Deviation of deflection from direct proportionality . . . . .	490
	Regulation of Static Transformers from "open" & "short circuit" tests, Deduction of . . . . .	410
133	— (by Differential method) Determination of . . . . .	410
139	— (in Single conversion method) . . . . .	412
	Resence Resistance Material, Table giving Rise of Temperature for Different Currents in . . . . .	618
	Resistance, Anti-Inductive, for Kelvin Standard Balances . . . .	653
	— Approximate Test for a very Low . . . . .	624
	— by Interpolation, Calculation of Exact . . . . .	83
34	— by the Post Office Wheatstone Bridge, Measurement of . . .	81
	— by the Wheat-stone Bridge, Proof of Formula giving . . . .	492
30	— Comparison of High, Medium, and Low (Potentiometer Method) . . . . .	94
44	— (Conductor), Measurement by Evershed's Bridge-Megger . . .	117
108	— Determination of the Non-inductiveness of a . . . . .	314
	— Fixed Standard Low . . . . .	604
	— General remarks on Insulation . . . . .	98 & 109
20	— Heated by a Current, Measurement of a . . . . .	46
	— (High) by the Direct Deflection Method, Solution of Infer- ences for . . . . .	493
	— Incandescent Lamp Box . . . . .	598
42	— (Insulation) by Silvertown Portable Testing Set . . . . .	105
49	— (Insulation) of Dynamos and Motors, etc. . . . .	129
	— (Insulation) of Electrical Mains and Installations . . . . .	98 & 109
47	— (Insulation) of Faulty Telegraph Insulators . . . . .	123
43	— (Insulation) of Installations, Cables, Machines, etc., by Evershed's Megger & Bridge-Megger Portable Testing Sets . .	113-116
45	— (Insulation) of Installations, etc., Measurement while working .	119
46	— (Insulation) of Installations, etc., Measurement while working . . . . .	121
48	— (Insulation) of Storage Batteries . . . . .	127
	— Low) by the Potential Difference Method, Solution of Inferences for . . . . .	492
40	— (Low), Measurement by Nalder Measurer . . . . .	87
37	— (Low), Measurement by Simple Potentiometer Method . . . .	83
38	— (Low), Measurement by Voltmeter and Ammeter Method . .	80
	— Material Table for Eureka . . . . .	646

# INDEX

686

Test No.		Page
	Resistance Material Table for Manganin . . . . .	649
	— Material Table for Nickel Chrome . . . . .	647
	— Material Table for Rocochem . . . . .	648
	— Measurer, Description of a Low . . . . .	521
	— of a Dynamo Circuit, Graphical way of finding the . . . . .	154
41	— of Cables (Three Deflection Method), Measurement of the Insulation . . . . .	99
35	— of Dynamo Armatures, Electric Light Cables, etc., Measurement of the . . . . .	81
	— of Dynamos and Motors, Proof of Formula giving Insulation . . . . .	426
	— of Electric Light Installations while working, Proof of Formula giving the Insulation . . . . .	494
	— of Liquids, Specific . . . . .	616
81	— of Magnet Coils, Rise of Temperature and increase in . . . . .	216
38	— of Metallic Conductors by Silvertown Portable Testing Set . . . . .	80
	— of Pure Metal and Alloys, Table of Specific . . . . .	614
32	— of Secondary Cells, Measurement of the Internal . . . . .	75
	— of Secondary Cells, Proof of Formula for the Internal . . . . .	491
	— of Single & Polyphase Windings, Measurement of . . . . .	243
	— of Storage Battery, Proof of Formula giving Insulation . . . . .	496
	— Siemens Bridge for Low . . . . .	525
	— Test by Siemens Low Resistance Bridge . . . . .	626
	Resonance (Pressure) in Series Circuits . . . . .	330
	— (Current) in Parallel Circuits . . . . .	334
	Retardation Method of Measuring Iron Loss in Alternators . . . . .	190
	Reversing Key, Sample . . . . .	685
	Revolving Contact Maker . . . . .	619
	Rheostat, Adjustable Carbon . . . . .	596
	— Adjustable . . . . .	600
	— Continuously variable . . . . .	600-604
	— Stand coil (step by step) . . . . .	606
	— Three-phase liquid . . . . .	607
81	Rise of temperature and increase in Resistance of Magnet Coils . . . . .	216
146 & 149	Rotary Converters, Efficiency of Multi-phase . . . . .	433 & 439
147	— Converters, No-Load Characteristic of . . . . .	438
149-152	— Converters, Other Tests on . . . . .	439-443
	— Converters, Synchronizing of . . . . .	441
145	— Rectifier, Efficiency of a . . . . .	431
52	Rotational Speed, Measurement of, by Stroboscopic Fork . . . . .	185
	Motor of an A.C. Motor, Definition of the . . . . .	270
129	Rowland's Method of Comparing Self-Induction by Alternating Currents . . . . .	366
127	— Method of Measuring Self-Induction absolutely by Alternating Currents . . . . .	362

## S

	Sark-Joint in Bare Wires . . . . .	478
	Screens (Bunsen's, Jolly's and Lummer-Brodhu's), Photometer . . . . .	502-5
	— (Methven's) Photometric Standard of Light . . . . .	695
48	Secondary Batteries, Measurement of the Insulation Resistance of . . . . .	127
33	— Cells, Measurement of the Efficiency and Storage Capacity of . . . . .	76
32	— Cells, Measurement of the Internal Resistance of . . . . .	75
	— Cells, Proof of Formula for the Internal Resistance of . . . . .	491

Test No.		Page
127	Self-Induction, Absolute Measurement (by Howland's A.C. Method) of . . . . .	343
128	— (by Impedance Method), Measurement, using Single-phase A.C.s of . . . . .	353
114	— Capacity, and Ohmic Resistance in Circuits, Effects of Frequency with . . . . .	323
129	— Comparison (by Alternating Current) of two Coefficients of . . . . .	355
118	— Impedance and Reactance with Position of Movable Core in Solenoidal Choker, Variation of . . . . .	339
	— (Impedance Method using Single-phase A.C.s), Proof of Formula . . . . .	498
119	— Impedance, Reactance, Current and Power, Effect of Length of Air Gap in a Closed Magnetic Circuit on . . . . .	341
126	— Impedance, Reactance of Alternators, Motors and Transformers, etc., by Alternating Currents . . . . .	358
129	— in Series and Parallel, Determination of Laws of Combination of . . . . .	366
	— in Series and Parallel, Proof of Laws of Combination . . . . .	493
127	— Measurement (by Bowland's A.C. Method) of . . . . .	362
57	Separately Excited Dynamo (at Constant Speed), Relation between External and Exciting Currents . . . . .	149
55	— Excited Dynamo, Determination of the "Characteristic" of a . . . . .	147
56	— Excited Dynamo, Internal Characteristic or Curve of Magnetization of . . . . .	148
53	— Excited Dynamo, Relation between Speed and E.M.F. in . . . . .	149
	Separation of Internal Losses in an Alternator . . . . .	189
	— of Internal Losses in Dynamos and Motors, by Houseman's Method . . . . .	204
	— of Internal Losses in Dynamos and Motors, by Kapp's Method . . . . .	203
124	— of Iron Losses by A.C. Frequency Method . . . . .	352
	Series Wound Dynamo, Critical Resistance at a given Speed in a . . . . .	154
58	— Wound Dynamo, Determination of External Characteristic of a . . . . .	150
	— Wound Dynamo, Determination of Total Characteristic of a . . . . .	152
59	— Wound Dynamo, Internal Characteristic or Curve of Magnetization of a . . . . .	156
89	— Wound Electro-Motors, Efficiency and B.H.P. of Direct Current . . . . .	241
90	— Wound Tramway Motors, Efficiency and B.H.P. of 500 Volt D.C. . . . .	245
69	Short-circuit Characteristic of an Alternator . . . . .	173
98	— and No-Load Test of Induction Motor . . . . .	267
137	— Test for Copper Losses in Transformers . . . . .	497
	Shunt Wound Dynamo, Critical Resistance of a . . . . .	159
60	— Wound Dynamo, Determination of Characteristic of a . . . . .	155
	— Wound Dynamo, Graphical Deduction of Total Characteristic in . . . . .	157
61	— Wound Dynamo, Internal Characteristic or Curve of Magnetization of a . . . . .	159
53	— Wound Dynamo, Relation between Speed and E.M.F. in . . . . .	149
99	— Wound Electro-Motors, Efficiency and B.H.P. of Direct Current . . . . .	243
	Siemens Dynamometer-Wattmeter . . . . .	580

Test No.	Page
Siemens Electro-Dynamometer . . . . .	577
— H.P. Transmission Dynamometer . . . . .	623
— Low Resistance Bridge . . . . .	525
— Torsional Spring Control Voltmeter . . . . .	575
Silvertown Portable Testing Set . . . . .	554
42 — Portable Testing Set, Insulation Resistance by . . . . .	105
23 — Portable Testing Set, Measurement of Metallic Resistance by the . . . . .	90
— Portable Testing Set, Table showing best way to work the . . . . .	92
Sine and other Curves of E.M.F. Waves of a Dynamo . . . . .	197
99 Single-phase A.C. Electro-Motors, Measurement of Efficiency and R.H.P. . . . .	269
142 — Phase A.C. Static Transformers, Efficiency by Blakesley's Method of . . . . .	422
140 — Phase A.C. Static Transformers, Efficiency by Double Conversion of . . . . .	414
139 — Phase A.C. Static Transformers, Efficiency by Single Conversion of . . . . .	412
141 — Phase A.C. Static Transformers, Efficiency by Sampson's Method of . . . . .	417
139-142 — Phase A.C. Static Transformers, Efficiency of . . . . .	412-424
105 — Phase Commutator Motors, Efficiency and R.H.P. of . . . . .	239
Slanting T-Joint in Electric Light Cable . . . . .	486
Slip in an A.C. Motor, Definition and Measurement of Magnetic . . . . .	250-252
Seamer Motor Testing Brakes . . . . .	637
Soldering Irons for Cable Joining . . . . .	474
118 Solenoidal Choker, Variation of Impedance, Resistance and Self-Induction with Position of Movable Core in . . . . .	339
Specific Gravities, Table of . . . . .	644
— Resistances of Liquids, Table of . . . . .	645
— Resistances of Metals and Alloys, Table of . . . . .	644
66 Speed and E.M.F. at which a Dynamo truly Compound, Determination of . . . . .	167
53 — and E.M.F. in Direct-Current Dynamos, Relation between . . . . .	140
62 — by Stroboscopic Fork, Measurement of . . . . .	136
— Frequency, and Slip by the Stroboscopic Method . . . . .	262
51 — Indicators, Calibration of . . . . .	134
58 — Voltage and Current with Brush Position on Commutator of D.C. Motors, Variation of . . . . .	239
68 — with E.M.F. in Alternators (at Constant Excitation), Variation of . . . . .	163
57 — with Excitation on Armature of D.C. Motors (at Constant Voltage) . . . . .	235
56 — with Voltage on Armature of D.C. Motors (at Constant Excitation) . . . . .	236
Speed-Torque Curves of an Induction Motor, General Form of . . . . .	295
Speeds of Target with Stroboscopic Fork, Table of . . . . .	140
Spherical Candle Power of an Electric Arc Lamp . . . . .	70
— Candle Power of an Electric Glow Lamp . . . . .	66
27 — C.P. and Efficiency, Determination of the effect of various Carbons on . . . . .	70
Spring tapping key, two-way high insulation . . . . .	588
— Transmission Dynamometer, Expression for amount of Coiling of Spring . . . . .	652
— Transmission Dynamometer, Stroud . . . . .	625

Test No.		Page
	Springs for Thompson's Steam-Engine Indicator, Table of . . .	138
	Square Roots for Kelvin Balances, Tables of Doubled . . .	656
	Squares of Numbers, Table of . . .	661
	Stand Coil Rheostat . . .	606
	Standard Cell, Preparation of the Clark . . .	604
	Standard Kelvin Balance . . .	646
	Standardization of Electrical Measuring Instruments, General remarks on the . . .	4
91	Starting Torque and Current in D.C. Motors, Relation between . . .	246
104	— Torque, Voltage, Current, and the Rotor Circuit Resistance of an Induction Motor, Relation between . . .	298
138	Static Transformers (from Differential Method) Determination of Regulation of . . .	410
	— Transformers (from "open" and Short Circuit Tests) Deduction of Regulation of . . .	410
	— Transformers, Fundamental Considerations relating to A.C. . .	400
	Stator of an A.C. Motor . . .	270
159	Steam-Engine Generating Sets, the Commercial Efficiency of . . .	468
	Stray Power in Dynamos and Motors . . .	220, 255
62	Stroboscopic Fork, Measurement of Rotational Speed by . . .	136
	— Target, the . . .	188
141	Sumpter's Method of Measuring the Efficiency of Single-phase Static Transformers . . .	417
102	Sumpter-Weikes Method of Testing Induction Motors . . .	288
76	Swinburne-Morley Method of Finding Distribution of Potential round Commutators . . .	201
95	Swinburne's Electrical Method of Measuring Efficiency and H.P. of Electro-Motors . . .	255
82	— Electrical Method of Measuring Efficiency of D.C. Dynamos . . .	219
	Switch, Change-over and Reversing . . .	582
	— Two-way sliding . . .	687
	Synchronizing Rotary Converter . . .	441
	Synchronous Alternating Current Motors . . .	269 & 305
100	— A.C. Motor, Variation of Excitation and Armature Current and the "V" with other Curves of a . . .	305
107	— A.C. Motors, Efficiency and H.P., etc., of . . .	309
	— A.C. Synchronous Motors, etc., by Lamp and "Synchroscope" . . .	306
	— Speed, Definition with Induction Motors of . . .	260
<b>T</b>		
61	Tachometers, Calibration of . . .	134-140
	Target, the Stroboscopic . . .	138
47	Telegraph Insulators, Measurement of the Insulation Resistance of faulty . . .	123
110	Temperature and Frequency in Circuits having Ohmic Resistance and Self-Induction only, Relation between . . .	319
	— Coefficient of Metals and Alloys, Table of . . .	644
	— Coefficient of variation of E.M.F. in Clark's and Weston Coils . . .	13, 17 & 643
81	— Rise and Increase in Resistance of Magnet Coils . . .	216
	Testing Sets, the Evershed . . .	639-646
	— the Silvertown . . .	634
	Thompson Steam-Engine Indicator . . .	531
	Thompson's Method of Sampling the E.M.F. of Armature Coils . . .	198



Test No.	Page
124 Three-Ammeter Method of Measuring the Electrical Power in A.C. Circuits . . . . .	383
142 Three-Dynamometer Method of Measuring Transformer Efficiency . . . . .	422
135 Three-phase A.C. Circuits, Measurement of Electrical Power in . . . . .	388 & 396
— Liquid Rheostat . . . . .	607
16 Three-Voltmeter Method of Calibrating a Wattmeter . . . . .	38
153 — Method of Measuring the Electrical Power absorbed in an A.C. Inductive Circuit . . . . .	379
— Method of measuring power in A.C. Circuits, Proof of Formula . . . . .	501
T-Joint between two Electric Light Cables on the slant . . . . .	485
— between two Gutta-percha-covered Wires . . . . .	484
— between two Lead-covered Electric Light Leads . . . . .	484
— between two single-wire Electric Light Leads . . . . .	477
— between two 7-stranded Electric Light Leads . . . . .	481
— between two 19-stranded Electric Light Leads . . . . .	482
— between 37-stranded Electric Light Leads . . . . .	483
91 Torque and Current of D.C. Motors, Relation between Starting . . . . .	245
163 — Efficiency, Slip, Load, etc., in an Induction Motor with Variable Rotor Circuit Resistance . . . . .	294
— exerted by a Motor, Expression for . . . . .	246
— exerted by Series Motors, Expression for . . . . .	241
— speed Curves of Induction Motor, General form of . . . . .	295
— "Total Characteristic" of an Alternator (analytically) . . . . .	179
— Characteristic " of an Alternator (graphically) . . . . .	180
— Characteristic " of Compound Dynamo (Long Shunt), Graphical deduction of the . . . . .	162
— Characteristic " of Compound Dynamo (Short Shunt), Graphical deduction of the . . . . .	164
— Characteristic " of Magneto Dynamo, Graphical deduction of the . . . . .	145
— Characteristic " of Series Dynamo, Graphical deduction of the . . . . .	152
— Characteristic " of Shunt Dynamo, Graphical deduction of the . . . . .	157
Trafer, Ewing's Magnetic Curve . . . . .	609
90 Tram and Railway Motors, B.H.P. and Efficiency of 500 Volt Direct Current . . . . .	245
Transformation Ratio in Induction Motors . . . . .	205
139 Transformers (by Differential Method) Determination of Regulation of . . . . .	410
137 — (by Short Circuit Test) Copper Losses in . . . . .	407
142 — Efficiency (by Blakesley's 3-dynamometer Method) of Alternating Current . . . . .	422
140 — Efficiency (by double conversion) of Alternating Current . . . . .	414
139 — Efficiency (by single conversion) of Alternating Current . . . . .	412
141 — Efficiency (by Sumpner's Method) of Alternating Current . . . . .	417
143 — Efficiency of Multi-phase Alternating Current . . . . .	424
139-142 — Efficiency of Single-phase Alternating Current Static . . . . .	412
— (from Open and Short Circuit Tests) Deduction of Regulation of . . . . .	410
— Fundamental Considerations relating to A.C. Static . . . . .	400
126 — Impedance, Reactance and Self-Ind. by Alternating Currents . . . . .	358
85 Transmission Dynamometer, Measurement of Efficiency of a Generator by a . . . . .	230

Test No.	Page
Transmission Dynamometer, Siemens H. P.	623
— Dynamometer, Spring	625
— of Power by belts	625
Trotter's Direct-reading Bar Photometer	589
— Illumination Photometer	590
Twist Joint between Gutta-percha-covered Wires	484
— Joint between Lead-covered Cable	483
— Joint between Single Core Electric Light Wire	476
— Joint between 7-stranded Electric Light Cable	476
— Joint between 19-stranded Electric Light Cable†	482
— Joint between 37-stranded Electric Light Cable	483
Two-phase A. C. Circuits, Measurement of Electrical Power in	393 & 395
Two-way high insulating spring tapping key	583
— ordinary simple sliding key	587

## U

Units, Table showing relation between practical and C. G. S.	643
Useful numbers and constants	645

## V

105 "V" Curves of Synchronous Motors, Determination of	306
88 Voltage, Current, and Speed with Brush Position on Commutator of D. C. Motors, Variation of	239
— "drop" of an Alternator with Load and Power Factor	174
— ratio of conversion in Multi-phase Rotaries	437
148 — ratio with excitation and speed in Rotaries, Variation of	439
86 — with Speed of Armature of D. C. Motors (at Constant Excitation), Variation of	236
Voltmeter, Useful details for obtaining a good copper	14
Volt Box for the Potentiometer	521
11 Voltmeter calibration by comparison with a Crompton Potentiometer	23
10 — calibration by comparison with a Kelvin Centi-Ampere Balance	22
9 — calibration by comparison with a Kelvin Composite Balance	21
8 — calibration by comparison with a Standard D'Arsonval Voltmeter	13
7 — calibration by Poggendorff's Method	16
12 — calibration of a High Tension Alternating Current	26
13 Voltmeters, Complete test for various sources of Error in Direct and Alternating Current	29
— Electrostatic	562
— Kelvin Multicellular Electrostatic	563
— Siemens Torsional Spring Control	575

## W

78 Waste Field of Dynamos, Determination of relative distribution of	207
117 Wattless or Idle Current and Load Current, Determination of the	336 & 390
14 Wattmeter calibration by comparison with a Kelvin Composite Balance	84

# INDEX

691

Test No.		Page
15	Wattmeter calibration by comparison with Standard Ammeter and Voltmeter . . . . .	37
16	— calibration of a High Tension, by application of Ohm's Law . . . . .	41
16	— calibration with Alternating Currents (3 Voltmeter Method) . . . . .	38
	Constant of a . . . . .	35
	Correcting Factor of a . . . . .	399
	— Siemens Dynamometer . . . . .	580
	— the conditions for and object of a . . . . .	404
156	Wave Form, by the Duddell Oscillograph . . . . .	461
154-5	— by Joubert Contact Maker . . . . .	446-451
102	Weeks-Simpson Method of testing 3-Phase Induction Motors . . . . .	288
	Weston (Calvinium) Standard Cell, E. M. F. with temperature of 13 & 643	
84	Wheatstone Bridge, Measurement of Resistance by the Post Office form of . . . . .	81
	— Bridge, Method of Measuring Resistance, Deriv. of Formula for . . . . .	492
	Windings, Resistance of Single and Polyphase . . . . .	263
	Wire-drawing, in Steam-Engines . . . . .	471
	— Gauges, Comparison of Different . . . . .	650















## PREFACE

THIS work is intended to form a systematic course of instruction in the very extensive field of testing connected with pure Electrical Engineering. While much has been written, from time to time, about the more elementary branch of testing in Electrical Physics, relating in a measure to Electrical Engineering, I believe that, so far, no extensive attempt has been made to treat the more advanced and practical portions of the subject in that systematic manner which it requires.

I, therefore venture to think that the present work, which not only embodies much of, if not all, the experimental work that it is usually possible to do at most colleges, but also many tests on heavier electrical machinery, together with a highly descriptive course on jointing Electric Light cables, should be eminently suitable for constituting the electrical laboratory practice in the second and third years of a complete course of instruction in Electrical Engineering, and in addition should be of considerable service to the electrical engineer in electrical works and central stations. As far as possible the tests have been arranged in the order in which they may be worked, when used as a course for students, but there are exceptions to this rule, owing to the advisability of keeping tests of a similar nature together. I have endeavoured to make the tests as complete and descriptive as possible, and applicable in the case of any college and testing room. Each test comprises—an *Introduction* giving the chief features, advantages, and disadvantages of the test, condensed as much as possible; the *Apparatus* necessary; the *Observations* to be carried out, in other words, a complete and carefully arranged digest of the method of carrying out the actual test, with a *Diagram of Apparatus* and connections represented symbolically; a *Tabular Form* indicating the most convenient and proper way of recording the observations; and finally, *Inferences* which can be drawn from the results of the test. These latter if conscient-

tiously worked out are calculated to cause the experimenter to think and reason for himself.

Following the series of tests is an Appendix, containing the Algebraical solutions of the various formula met with in the tests, and these the student is strongly urged not to refer to until he has tried, by all the means in his power, to solve the inference for himself.

The Appendix also contains complete descriptions and illustrations of a large amount of the apparatus which may be employed in carrying out the tests, a considerable proportion of it being such as will be found in almost every college and testing-room.

Useful constants and tables which are frequently needed in electrical engineering tests are added at the end of the book. A good deal of the apparatus illustrated has been constructed by the mechanical assistants, Messrs. John Watkinson and Herbert Addy, of the Electrical Engineering Department of the University, Leeds.

In conclusion, I wish to express my sincere thanks to my valued friend, Mr. Charles Moreau, M.A., for the very considerable amount of trouble he has taken in producing the photographs from which many of the illustrations are obtained; to Dr. John Henderson, for permission to use the tables of squares and reciprocals of numbers; to Messrs. Kelvin & James White, for permission to use the tables of doubled square roots; to His Majesty's Stationery Office, for allowing me to use the tables of logarithms and anti-logarithms; to Messrs. Longmans, Green & Co., for their kindness in lending eight illustrations and a little printed matter from *Practical Electrical Testing*; to Mr. Herbert Addy, for the trouble he has taken in making the drawings from which the illustrations of joints, made in electric light cables, are taken, and also for reading through the proofs simultaneously with myself; and further to Messrs. Nalder Bros. & Co., Kelvin & James White, Siemens Bros. & Co., Crompton & Co., and Evershed & Vignoles, for their kindness in lending me the blocks of some of the illustrations of the very excellent apparatus and appliances made by them.

G. D. A. P.

*The University, Leeds.*

## PREFACE TO THE FOURTH EDITION

While opportunity has been taken, in previous editions, to both enlarge and improve the book, the scope of it has undergone very considerable extension and rearrangement in the present edition. Of some 192 extra pages of new matter, no less than 116 represent entirely new tests, including a little additional theoretical explanatory matter to the previously existing tests, while the remainder comprise descriptive matter and tables of useful figures.

Some of the new tests are of a direct current nature and bring the direct current portion of the book more thoroughly up-to-date; but the remainder, forming by far the greater proportion of new tests, relate to alternating currents. This branch of practical work—always more difficult to understand than that of direct currents—has therefore been greatly strengthened by additional matter dealing with modern theory, laboratory and commercial tests supplemented by vector diagrams which enable the phase relations between current and pressure to be more easily understood.

Further, the greater portion of the work has been completely rearranged so as to have all tests of a like nature together, though not necessarily numbered in the order in which they should be taken. The author therefore hopes that this edition will be found to offer many advantages over previous ones, and he will welcome notification of any errors which may have escaped observation before going to press.

I would like to thank my friends who have so kindly helped me to read through the proofs of this edition simultaneously with myself; also Messrs. Evershed & Vignoles, Naldor Bros. & Co., and Elliott Bros. Ltd., for their kindness in lending me additional blocks of illustrations of apparatus; and Messrs. The London Electric Wire Co., Smiths Ltd., for permission to reprint their Tables of Resistance Wires.

G. D. A. P.

January 1922.

## EDITORIAL NOTE

THE DIRECTLY-USEFUL TECHNICAL SERIES requires a few words by way of introduction. Technical books of the past have arranged themselves largely under two sections: the Theoretical and the Practical. Theoretical books have been written more for the training of college students than for the supply of information to men in practice, and have been greatly filled with descriptions of an academic character. Practical books have often sought the other extreme, omitting the scientific basis upon which all good practice is built, whether discernible or not. The present series is intended to occupy a midway position. The information, the problems, and the exercises are to be of a directly-useful character, but must at the same time be wedded to that proper amount of scientific explanation which alone will satisfy the inquiring mind. We shall thus appeal to all technical people throughout the land, either students or those in actual practice.









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## APPENDIX

### PROOFS OF FORMULAE

#### Deviation of the deflections of Reflecting Galvanometers from the direct proportional law.

It has been stated on p. 6 that the scale deflections of a D'Arsonval galvanometer are *directly proportional* to the currents producing them. Though this is not rigorously correct, it is sufficiently true for most practical purposes in the usual forms of instruments belonging to this class. For very accurate work, however, it is necessary to apply a correction, usually amounting to a small fraction of 1% for deviation from this law, and this we now proceed to indicate.

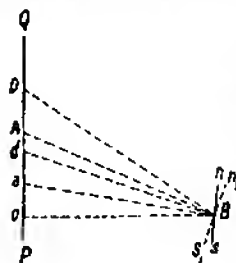


FIG. 202.

Let  $O$  be the zero of the scale  $PQ$ , presumably in the centre, though, for convenience, only one-half of the scale is shown, and let  $Od$  and  $OD$  be the scale deflections of the spot of light on  $PQ$  from zero for currents  $C_1$  and  $C_2$  through the galvanometer coil.

If  $B$  is the centre of the needle  $ns$ , then  $OB$  is the incident ray of light from some source at  $O$  and  $Bd$ ,  $BD$  the reflected rays for the two positions of the mirror and its attached needle  $ns$ .

By drawing the normals to the mirror in each position we get

$Ba$  and  $BA$  respectively, and it can at once be shown that the angle  $dED = 2aBA$ , or that the angular motion of the mirror is half that of the reflected ray.

Now since  $ns$  is contained by the plane of its coil for no current and is parallel to  $PQ$ , we shall always have (for the small angular motion of  $ns$  usually obtained in mirror galvanometers)—

$$\begin{aligned} C_1 : C_2 &= \tan. \frac{1}{2} OAd : \tan. \frac{1}{2} OBD, \\ &= \tan. \frac{1}{2} \frac{Oa}{OB} : \tan. \frac{1}{2} \frac{OB}{OB}, \\ &= \frac{\sqrt{1 + \left(\frac{Oa}{OB}\right)^2} - 1}{\frac{Oa}{OB}} : \frac{\sqrt{1 + \left(\frac{OB}{OB}\right)^2} - 1}{\frac{OB}{OB}} \quad (\text{accurately}), \end{aligned}$$

or if  $Oa$  and  $OB$  are not very different and are small, then—

$$C_1 : C_2 = Oa : OB \quad (\text{approximately}).$$

### Measurement of the Internal Resistance of Secondary Cells. (Fall of Potential Method.)

**Proof of Formula.**—Referring to p. 76, let  $E$  = the total E.M.F. of the cell or battery, and  $V$  the potential difference at its terminals, when sending a current  $A$ .

If then  $R$  is the internal resistance of the cell and  $R$  the resistance of the external circuit, we have by Ohm's Law—

Fall of Potential round external circuit =  $AR = V$ ,  
and " " in the cell itself =  $AB$ .

Hence we must have  $E = AR + AB = A(R + B)$ .

But the Fall of Potential in the cell itself is also =  $E - V$ ,

$$\therefore E - V = AB,$$

$$\text{and} \quad \therefore B = \frac{E - V}{A} \text{ ohms;}$$

$$\text{or thus} \quad \frac{E}{V} = \frac{A(R + B)}{AR}$$

$$\text{Hence} \quad B = \frac{E - V}{V} R, \text{ but } AR = V, \text{ or } R = \frac{V}{A}$$

$$\therefore B = \frac{E - V}{A} \text{ ohms.}$$

### Measurement of Resistance. (Wheatstone Bridge Method.)

**Proof of Formula.**—Referring to Fig. 33 I, p. 82, let  $V_1$ ,  $V_2$  and  $V_3$  = the Potentials of the points  $P$ ,  $N$  and  $T$  respectively; then the point  $Q$  will also be at the potential  $V_2$ , since when the bridge is "balanced" no deflection will occur on the galvanometer, owing to there being no difference of potential between  $N$  and  $Q$  to cause a current to flow. Now let  $C_1$ ,  $C_2$ ,  $C_3$  and  $C_4$  be the currents passing through the resistances  $r_1$ ,  $r_2$ ,  $r_3$  and  $r_4$  respectively of the arms of the bridge.

$$\begin{aligned}\text{Then} \quad V_1 - V_2 &= C_2 r_2 = C_4 r_4, \\ \text{and} \quad V_2 - V_3 &= C_1 r_1 = C_3 r_3;\end{aligned}$$

but since on balance being obtained no current flows through the galvanometer, i. e. between the points  $N$  and  $Q$ , we get

$$C_1 = C_4 \quad \text{and} \quad C_2 = C_3,$$

$$\text{whence by division} \quad \frac{C_2 r_2}{C_3 r_3} = \frac{C_4 r_4}{C_1 r_1}$$

$$\text{or} \quad \frac{r_2}{r_3} = \frac{r_4}{r_1}$$

$$\text{and} \quad \therefore r_1 r_2 = r_3 r_4.$$

The resistance in the galvanometer and battery circuits is immaterial, so long as it is not great enough to diminish the sensitiveness of the tests; consequently it may vary without vitiating the results at all.

### Measurement of Low Resistance. (Potential Difference Method.)

**Solution of Inference.**—Referring to Fig. 34, p. 85, let  $A$  = current flowing through the resistances  $r$  and  $R$  in series, and  $v$ ,  $V$  = Potential Differences across their extremities respectively.

Then from Ohm's Law we have

$$A = \frac{V}{R} = \frac{v}{r}$$

but since the galvanometer resistance is high compared with

either  $r$  or  $R$ , we have its deflections  $d_r$  and  $d_R$  across these resistances respectively proportional to  $v$  and  $V$ , whence

$$\frac{d_R}{R} = \frac{d_r}{r}$$

and  $\therefore$  the unknown resistance, assumed to be ( $r$ ), is

$$r = \frac{d_r}{d_R} R \text{ ohms.}$$

**Assumptions.**—(1) That no fluctuations of the current  $I$  have occurred in the interval of time between the observations  $d_R$  and  $d_r$  of any particular pair.

(2) That the introduction of the galvanometer across the resistance has not altered the P.D. at their respective terminals.

(3) That the deflections are proportional to the currents, which is very nearly true for ordinary reflecting instruments.

**Errors** may arise from the warming up of the resistances to be compared, due to the passage of the current, and the consequent alteration of resistance. The current should not be strong enough to do this.

Also from the presence of thermo currents caused by the warming up of a junction of two dissimilar metals.

Lastly, from the inconstancy of the current, which can be minimized by taking readings with one of the resistances *before* and after that with the other, and noting the mean of the two.

## Measurement of very high or Insulation Resistance. (Direct Deflection Method.)

**Solution of Inferences.**—Referring to p. 101—

Let  $b$  = the internal resistance of the battery,

$g$  = the galvanometer resistance,

$C_R C_r$  = the currents through the galvanometer, causing deflections  $d_R d_r$ , when the resistances  $R$  and  $r$  are in circuit respectively and  $K$  be a constant converting these deflections to actual currents.

Then if  $E$  is the E.M.F. of the battery we have by Ohm's Law

$$C_R = K d_R = \frac{S_R}{S_R + g} \times \frac{E}{R + b + \frac{S_R g}{S_R + g}} = \frac{S_R E}{(R + b)(S_R + g) + g S_R}$$



$$\text{Similarly } C_r = Kd_r = \frac{S_r}{S_r + g} \times \frac{E}{r + b + \frac{S_r g}{S_r + g}} = \frac{S_r E}{(r + b)(S_r + g) + gS_r}$$

whence by division

$$\frac{d_R}{d_r} = \frac{(r + b)(S_r + g) + gS_r}{(R + b)(S_R + g) + gS_R} \times \frac{S_R}{S_r}$$

Now  $b$  will always be negligibly small compared with  $R$  or  $r$ .

$$\text{Hence } \frac{d_R}{d_r} = \frac{r(S_r + g) + gS_r}{R(S_R + g) + gS_R} \times \frac{S_R}{S_r} = \frac{r\left(1 + \frac{g}{S_r}\right) + g}{R\left(1 + \frac{g}{S_R}\right) + g}$$

$$\text{or } d_R \left[ R \left( 1 + \frac{g}{S_R} \right) + g \right] = d_r \left[ r \left( 1 + \frac{g}{S_r} \right) + g \right] \quad (1)$$

When no shunts are used  $S_R$  and  $S_r$  both = infinity and

$$d_R(R + g) = d_r(r + g)$$

Lastly, if  $(g)$  is negligibly small compared with  $R$  and  $r$ , then

$$d_R R = d_r r,$$

and

$$\therefore r = \frac{d_R}{d_r} R \dots \dots \dots (2)$$

The assumption made in both formulas 1 and 2 above are that—

(a) The E.M.F. of the testing battery remains constant throughout the tests, which is justifiable owing to its working through such high resistances.

(b) The internal resistance of the battery is so small compared with  $R$  and  $r$  as to be quite negligible.

In the relation (2) above, it is assumed that—

(c) No shunts are used at all with the galvanometer.

(d) The galvanometer resistance  $(g)$  is so small compared with  $R$  and  $r$  as to be quite negligible.

## Insulation Resistance of Electric Light Installations while working.

**Solution of Inferences.**—Let  $A$  and  $B$  be the two points of the circuit most convenient for attaching the wires to, that come from the two-way key  $K$ . Let  $r_v$  = resistance of the voltmeter, and  $R_1 R_2$  = insulation resistances of the +ve and -ve sides, respectively,

of the network or installation, in ohms. Then that of the whole system, everything included, is  $R = \frac{R_1 R_2}{R_1 + R_2}$ .

In Fig. 203,  $E$  represents the earth or nearest gas or water-pipe.

If then  $V_1$  and  $V_2$  are the voltmeter readings when placed between the +ve and -ve sides of the circuit and earth, and  $V$  the voltage between the mains, we have

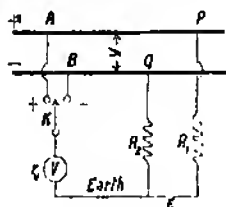


FIG. 203.

$$\text{Fall of P.D. between A and E, viz. } V_1 = V \frac{\frac{R_1 r_v}{R_1 + r_v}}{\frac{R_1 r_v}{R_1 + r_v} + R_2}$$

$$\text{Similarly the fall of P.D. between B and E, viz. } V_2 = V \frac{\frac{R_2 r_v}{R_2 + r_v}}{\frac{R_2 r_v}{R_2 + r_v} + R_1}$$

Since  $EPA$  and  $EV_1$  are in parallel, and the combination in series with  $BQB$ ,

$$\therefore V_1 + V_2 = V \frac{(R_1 + R_2) r_v}{(R_1 + R_2) r_v + R_1 R_2}$$

$$\therefore \frac{1}{V_1 + V_2} = \frac{1}{V} \left( 1 + \frac{R_1 R_2}{R_1 + R_2} \frac{1}{r_v} \right)$$

or

$$R = r_v \left( \frac{V}{V_1 + V_2} - 1 \right)$$

also

$$R_2 = R \frac{V_1 + V_2}{V_1} = r_v \left[ \frac{V - (V_1 + V_2)}{V_1} \right]$$

$$R_1 = \frac{r_v [V - (V_1 + V_2)]}{\frac{V}{V_2} - 1}$$

( $V_1 + V_2$ ) representing the absolute sum of the two voltages, assuming they are to opposite sides of zero.

### Insulation Resistance of a Storage Battery.

**Solution of Inferences.**—Referring to Fig. 50, p. 128—

Let  $P_1 P_2 P_3 \dots$  be points on the battery which are partially earthed,

$R_1 R_2 R_3 \dots$  be the resistances of these earths,

$C_1 C_2 C_3 \dots$  be the currents flowing from  $P_1 P_2$  and  $P_3 \dots$  to earth when  $G$  is connected,  $K$  closed, and  $r=0$ ,

$E_1 E_2 E_3 \dots$  the E.M.F.s between  $P$  and  $P_1 P_2 P_3 \dots$  respectively.

Then if all the currents flow from battery to earth

$$\begin{array}{ll} C_1 R_1 - C_g g = E_1, & C_g g - C_3 R_3 = E_3, \\ C_2 R_2 - C_g g = E_2, & C_g g - C_4 R_4 = E_4, \\ \text{etc.} & \text{etc.} \end{array}$$

Also

$$C_1 + C_2 + C_3 + \dots + C_g = 0.$$

Hence—

$$\frac{E_1 + C_g g}{R_1} + \frac{E_2 + C_g g}{R_2} + \dots + \frac{C_g g - E_3}{R_3} + \frac{C_g g - E_4}{R_4} + \dots + C_g = 0.$$

Now when  $C_g$  falls to  $C_r$  by increasing  $g$  to  $(g+r)$  we have

$$\begin{aligned} & \frac{E_1 + C_r(g+r)}{R_1} + \frac{E_2 + C_r(g+r)}{R_2} + \dots + \frac{C_r(g+r) - E_3}{R_3} \\ & + \frac{C_r(g+r) - E_4}{R_4} + \dots + C_r = 0. \end{aligned}$$

Hence from the difference of these two equations we have

$$\{C_g g - C_r(g+r)\} \left( \frac{1}{R_1} + \frac{1}{R_2} + \dots \right) + C_g - C_r = 0,$$

whence

$$R = \frac{C_g g - C_r(g+r)}{C_r - C_g}$$

### Insulation Resistance of Dynamos and Motors.

**Solution of Inferences.**—The proof of the formula employed in this test is precisely the same as that given on p. 494 for the insulation resistance of electric light installations. It will not therefore be repeated here.

### Efficiency of Direct-Current Generators. (Hopkinson's Electrical Method.)

**Solution of Inferences.**—Referring to Fig. 85, p. 234, let  $V_1, V_2, V_3$  be the terminal voltages of  $\alpha, \beta$  and  $\gamma$  respectively, and  $A$  the main current through them all. Then we have—

Power developed by the generator  $\alpha = AV_1$  Watts

„ supplied by the auxiliary  $\gamma = AV_3$  „

„ given to the motor  $\beta = AV_2$  „

Hence  $AV_3 = AV_2 - AV_1 = A(V_2 - V_1)$

which is the power lost in both machines together.

If  $V$  = normal working pressure of  $\alpha$  and  $\beta$  when running as dynamos,  $r_a$  and  $r_\beta$  = normal resistances of their shunts.

Then  $\frac{V^2}{r_a}$  and  $\frac{V^2}{r_\beta}$  = Watts wasted in their respective shunt

circuits, neglecting any extra resistance such as  $R_1$  and  $R_2$ . Now let the total internal loss in  $\alpha$  = that in  $\beta$ . Then—

Efficiency of dynamo  $\alpha$

$$\Sigma_\alpha = \frac{\text{useful power developed}}{\text{total power put in}} = \frac{AV_1}{\frac{1}{2}AV_2 + AV_1 + \frac{V^2}{r_a}}$$

Efficiency of motor  $\beta$

$$\begin{aligned} \Sigma_\beta &= \frac{\text{useful B.H.P. developed}}{\text{total E.H.P. put in}} = \frac{-\frac{1}{2}AV_2 + AV_1 + \frac{V^2}{r_\beta}}{AV_2 + \frac{V^2}{r_\beta}} \\ &= \frac{\frac{1}{2}A(V_2 + V_1) + \frac{V^2}{r_\beta}}{AV_2 + \frac{V^2}{r_\beta}} \end{aligned}$$

If now we neglect the shunt losses  $\frac{V^2}{r_a}$  and  $\frac{V^2}{r_\beta}$  in comparison with the outputs of  $\alpha$  and  $\beta$ , then

$$\Sigma_\alpha \approx \frac{2V_1}{V_1 + V_2} \quad \text{and} \quad \Sigma_\beta \approx \frac{V_1 + V_2}{2V_2}$$

$$\therefore \Sigma_\alpha \Sigma_\beta \approx \frac{V_1}{V_2}$$

K K

Lastly, if we assume that the machines are so alike that

$$\Sigma_a = \Sigma_b = \Sigma \text{ (say)}$$

$$\text{Then} \quad \Sigma^2 = \frac{V_1^2}{V_2^2} \quad \text{or} \quad \Sigma = \sqrt{\frac{V_1}{V_2}}$$

which is therefore the efficiency of either machine.

### Self-Induction by the Impedance Method using Single-Phase Alternating Currents.

**Solution of Inferences.**—Referring to Fig. 132, p. 360, let  $V_a$  and  $V_b$  be the readings of the voltmeter when an alternating and direct current of the same strength  $A$  is successively passed through the self-induction whose value  $L$  is to be determined.

Let  $n$  = frequency of the alternating current in  $\sim$  per sec., then its angular velocity  $p = 2\pi n$ .

If  $R$  = the ohmic resistance of the self-inductive circuit we have for the direct current, by Ohm's Law,

$$R = \frac{V_b}{A} \text{ ohms,}$$

and for the alternating current we have

$$\frac{V_a}{A} = \sqrt{L^2 p^2 + R^2} \text{ the impedance of the circuit.}$$

$$\text{Hence by substitution } \frac{V_a}{A} = \sqrt{(Lp)^2 + \left(\frac{V_b}{A}\right)^2}$$

$$\text{or} \quad \left(\frac{V_a}{A}\right)^2 = (Lp)^2 + \left(\frac{V_b}{A}\right)^2$$

$$\text{whence} \quad L^2 p^2 = \left(\frac{V_a}{A}\right)^2 - \left(\frac{V_b}{A}\right)^2 = \frac{1}{A^2} \{V_a^2 - V_b^2\}$$

$$\text{and} \quad \therefore L = \frac{1}{pA} \sqrt{V_a^2 - V_b^2} \text{ henries,}$$

### Self-Inductions in Series and Parallel Laws of Combination.

**Proof of Formula.**—Suppose that we first take the arrangement represented in Fig. 135  $\gamma$ , p. 367, in which all the self-inductions  $L_1$ ,  $L_2$ ,  $L_3$  and  $L_4$  are in parallel.

Let them possess ohmic resistance  $R_1, R_2, R_3$ , and  $R_4$ , respectively, but no mutual induction.

Also let  $L_0$  and  $R_0$  be the combined or equivalent self-induction and ohmic resistance of the combined parallel circuit such that if substituted for the parallel branches the same potential difference  $V$  would exist at the terminals, causing the same current  $A$  to flow through.

If then the angular velocity of the alternating current be denoted as usual, by  $p = 2\pi n$  where  $n$  is the periodicity, we can apply the solution obtained by Lord Rayleigh for the impedance of parallel circuits and given in a paper by him "On Forced Harmonic Oscillations of Various Periods."—*Phil. Mag.*, May 1886.

$$\text{Thus} \quad I_0 = \frac{B}{A^2 + L_0^2 p^2} \quad \text{and} \quad R_0 = \frac{A}{A^2 + L_0^2 p^2}$$

$$\text{where} \quad A = \sum \left( \frac{R}{L^2 p^2 + R^2} \right) \quad \text{and} \quad B = \sum \left( \frac{L}{L^2 p^2 + R^2} \right)$$

$$\text{Hence} \quad \frac{V}{A} = \sqrt{L_0^2 p^2 + R_0^2} = \sqrt{\frac{1}{A^2 + L_0^2 p^2}}$$

Substituting the values of  $A$  and  $B$  given above we get

$$\begin{aligned} \frac{V}{A} &= \sqrt{L_0^2 p^2 + R_0^2} = \sqrt{\frac{1}{\left( \sum \frac{L}{L^2 p^2 + R^2} \right)^2 + \left( \sum \frac{R}{L^2 p^2 + R^2} \right)^2}} \\ &= \sqrt{\frac{1}{\left( \sum \frac{L}{L^2} \right)^2 p^2 + \left( \sum \frac{R}{R^2} \right)^2}} \end{aligned}$$

Next take the arrangement shown in Fig. 135  $\beta$ , in which the inductions are connected up, two in series and two in parallel.

Here, since self-inductions in series sum up like resistance in series, we have, applying the last equation for two parallel branches, that

$$\begin{aligned} \frac{V}{A} &= \sqrt{L_0^2 p^2 + R_0^2} \\ &= \sqrt{\frac{1}{\left( \frac{R_1 + R_2}{(L_1 + L_2)^2} + \frac{R_3 + R_4}{(L_3 + L_4)^2} \right)^2 + \left( \frac{L_1 + L_2}{(L_1 + L_2)^2} + \frac{L_3 + L_4}{(L_3 + L_4)^2} \right)^2 p^2}} \\ &= \sqrt{\frac{(L_1 + L_2)(L_3 + L_4)}{(L_1 + L_2 + L_3 + L_4)^2 p^2 + (R_1 + R_2 + R_3 + R_4)^2}} \end{aligned}$$

$$= \frac{\sqrt{(L_1 + L_2)^2 I^2 + (R_1 + R_2)^2} \sqrt{(L_3 + L_4)^2 I^2 + (R_3 + R_4)^2}}{\sqrt{(\Sigma L)^2 I^2 + (\Sigma R)^2}}$$

which is the combined or effective or equivalent impedance of this particular branched circuit.

### Electrostatic Capacity of Electrical Cables. (Multicellular Voltmeter Method.)

**Proof of Formula.**—Let  $C_a$  = capacity of the standard air condenser;  $C_L$  = capacity of the cable, and  $K_1, K_2$  = capacities of the voltmeter at the potentials  $V_1$  and  $V_2$  respectively.

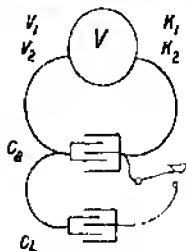


FIG. 204.

Then if  $C_a$  is first charged in parallel with  $V$  to a potential  $V_1$ , the quantity of electricity in the charge is  $Q_1 = V_1 (C_a + K_1)$ , since the capacities  $C_a$  and  $K_1$  are in parallel.

If now  $K$  is closed so as to put  $C_L$  in parallel with the first two and the potential falls in consequence to  $V_2$ , the quantity of the charge is still the same assuming no leakage, and we have

$$Q_1 = V_2 (C_a + C_L + K_2).$$

Hence  $V_1 (C_a + K_1) = V_2 (C_a + C_L + K_2)$

or  $\frac{V_2}{V_1} = \frac{C_a + K_1}{C_a + C_L + K_2}$

and by a well-known rule in proportion we have

$$\frac{V_2}{V_1 - V_2} = \frac{C_a + K_1}{C_a + C_L + K_2 - C_a - K_1} = \frac{C_a + K_1}{C_L + K_2 - K_1}$$

$$\therefore V_2 C_L + V_2 K_2 - V_2 K_1 = V_1 C_a - V_2 C_a + V_1 K_1 - V_2 K_1.$$

Hence  $V_2 C_L + V_2 K_2 = C_a (V_1 - V_2) + V_1 K_1$

and  $\therefore C_L = \frac{C_a (V_1 - V_2) + V_1 K_1 - V_2 K_2}{V_2}$

or neglecting the capacity of the voltmeter in comparison with

$C_a$  and  $C_L$  we have  $C_L = C_a \frac{V_1 - V_2}{V_2}$

### Capacity of Concentric Cables. (Standard Magneto Inductor Method.)

**Proof of Formula.**—Referring to the test, p. 377, let  $N$  be the number of turns of wire on the standard inductor and  $F$  the total number of lines of magnetic force threading the gap, then the interlinking of turns and field =  $FN$ .

If now  $R$  = the total resistance in ohms of the inductor circuit, the whole quantity of electricity  $Q_1$  producing the throw  $d_1$  is

$$Q_1 \propto d_1 \propto \frac{NF}{R}.$$

Again, let  $C$  = the capacity of the cable in microfarads,  $V$  = the potential difference in volts to which it is charged, then the quantity of electricity  $Q_2$  causing the throw  $d_2$  is

$$Q_2 \propto d_2 \propto CV,$$

and 1 microcoulomb =  $\frac{10^{-1}}{10^9} = 10^{-10}$  C.G.S. units of quantity,

also 1 ohm =  $10^9$  C.G.S. units of resistance

$$\text{Hence } \frac{d_1}{d_2} = \frac{FN}{10^{-10} \times 10^9 \times K \sqrt{C}} = \frac{FN}{100 K \sqrt{C}}$$

and  $\therefore C = \frac{FN}{100 K \sqrt{V}} \frac{d_2}{d_1}$  microfarads.

For the greatest accuracy we ought to have

$$d_1 = d_2$$

### Three Voltmeter Method of Measuring the "True Electrical Power" in Single-Phase Alternating Current Circuits.

**Solution of Inferences.**—Referring to Fig. 140, p. 383, let the  $\sqrt{\text{mean square}}$  value of the voltages, as given by either a hot wire or electrostatic voltmeter, be denoted by  $V$ ,  $V_1$  and  $V_2$  for the positions shown in the figure; also let  $(r)$  = the value of the non-inductive resistance  $QR$  in ohms.

Then we require the value of the *mean* or True Power in Watts  $W$  given to the whole circuit  $PR$  in which the whole power is absorbed; let  $v$ ,  $v_1$  and  $v_2$  be the instantaneous values of the



voltages corresponding to the  $\sqrt{\text{mean square values}}$   $V, V_1$  and  $V_2$ , respectively at any instant ( $t$ ), then  $v = v_1 + v_2$ ; also, if  $i$  = instantaneous current in amps. flowing through  $PR$  at this same instant  $t$ , we have the instantaneous value of the power in Watts ( $w$ ) given to  $PR$  at that instant as  $w = vi$ ;

but we also have  $i = \frac{v_2}{r}$ , since  $QR$  is non-inductive,

$$\text{whence } w = vi = v \cdot \frac{v_2}{r} = \frac{vv_2}{r}$$

or

$$vv_2 = wr;$$

now since

$$v = v_1 + v_2$$

$$\therefore v_1 = v - v_2$$

and

$$2v_1v_2 = 2v_2(v - v_2) = 2vv_2 - 2v_2^2.$$

Hence by substitution  $2v_1v_2 = 2wr - 2v_2^2$ ;

but

$$v^2 = v_1^2 + 2v_1v_2 + v_2^2 \quad \text{by squaring,}$$

$$\therefore v^2 = v_1^2 + 2(wr - 2v_2^2) + v_2^2 \quad \text{by substitution.}$$

Hence

$$w = \frac{1}{2r} \{ v^2 - v_1^2 + v_2^2 \}.$$

Integrating this equation for the period  $T$  we get

$$\int_0^T w dt = \frac{1}{2r} \left\{ \int_0^T v^2 dt - \int_0^T v_1^2 dt + \int_0^T v_2^2 dt \right\}$$

and finally

$$W = \frac{1}{2r} \{ V^2 - V_1^2 + V_2^2 \}.$$

### Efficiency of Transformers. (Blakesley's Three Dynamometer Method.)

**Solution of Inferences.**—Referring to p. 423, on which will be found a formula derived by Mr. Blakesley for expressing the power given to the primary of a transformer in his method of measuring the efficiency of such an appliance, Professor Ayrton and Mr. Taylor have deduced the following general proof of this relation, which makes no assumption whatever as to the nature of the current, whether sinusoidal or otherwise, but only that there is no magnetic leakage between primary and secondary windings. This is approximately true for "closed circuit" though not for "open circuit" transformers, so that the method cannot be considered a very good one.

Let  $a_1, a_2$  = instantaneous values of the currents and  $v_1, v_2$  those of the E.M.F.s in the primary and secondary windings having  $N_1, N_2$  turns respectively, and  $B$  = the mean density of lines in the core, then if  $R_1, R_2$  = ohmic resistances of the primary and secondary

we have 
$$v_1 = R_1 a_1 + \frac{N_1}{10^8} \frac{dB}{dt}.$$

But 
$$\frac{N_2}{10^8} \frac{dB}{dt} = R_2 a_2 \text{ since we assume no leakage,}$$

$$\therefore v_1 = R_1 a_1 + \frac{N_1}{N_2} R_2 a_2;$$

multiplying all through by  $a_1$  we get

$$v_1 a_1 = R_1 a_1^2 + \frac{N_1}{N_2} R_2 a_1 a_2.$$

Integrating this last equation between the limits of the period  $T$  we get

$$\frac{1}{T} \int_0^T v_1 a_1 dt = \frac{R_1}{T} \int_0^T a_1^2 dt + \frac{N_1}{N_2} \frac{R_2}{T} \int_0^T a_1 a_2 dt.$$

Hence if  $A$  is the split dynamometer reading we finally have

$$W_P = A_1 R_1 + \frac{N_1}{N_2} R_2 A$$

## APPARATUS

### Preparation of the Clark Standard Cell.

**Definition of the Cell.**—The cell consists of zinc and mercury in a saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess, and is conveniently contained in a cylindrical glass vessel.

**Preparation of Materials.**—*The Mercury.*—To secure purity it should be first treated with acid in the usual way, and subsequently distilled in vacuum.

*The Zinc.*—Take a portion of a rod of pure zinc, and solder to one end a piece of copper wire. Clean the whole with glass paper, carefully removing any loose pieces of zinc. Just before making up the cell, dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

*The Zinc Sulphate Solution.*—Prepare a saturated solution of pure (re-crystallized) zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding a little zinc carbonate, in the proportion of about 2 per cent. by weight of zinc sulphate crystals, to neutralize any free acid. The whole of the crystals should be dissolved with the aid of *gentle heat*, i. e. not greater than 30° C., and the solution filtered while still warm into a stock bottle. Crystals should form as it cools.

*The Mercurous Sulphate.*—Take mercurous sulphate sold as pure, which is white, and wash it thoroughly with cold distilled water by agitation in a flask; drain off the water, and repeat the process at least twice, but after the last washing, drain off as much

water as possible. Mix the washed sulphate, in the proportion of about 12 per cent. by weight of  $ZnSO_4$  crystals, with the zinc sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to ensure saturation, and a small quantity of pure mercury. Shake them well up together to form a paste of the consistency of cream. Heat the paste sufficiently to dissolve the crystals, but not above  $30^{\circ}C$ . Keep the paste for one hour at this temperature, agitating it from time to time, and then allow it to cool.

Crystals of zinc sulphate should then be distinctly visible throughout the mass. If this is not the case, add more crystals from the stock bottle, and repeat the process. This method ensures the formation of a saturated solution of zinc and mercurous sulphates in water. The presence of the free mercury throughout the paste preserves the basicity of the salt, and is of the utmost importance. Contact is made with the mercury by means of a platinum wire about No. 22 B.W.G., which is prevented from making contact with the other materials of the cell by being sealed into a glass tube, the ends of the wire projecting beyond those of the tube. One end forms the terminal; the other end, and part of the glass tube, dip into the mercury.

**To set up the Cell.**—The cell may be conveniently set up in a small test tube of about 2 cms. in diameter and 6 or 7 cms. deep.

Place the mercury in the bottom of this tube, filling it to a depth of, say, 1.5 cms.

Cut a cork about 0.5 cm. thick to fit the tube. At one side of the cork bore a hole through which the zinc rod can pass tightly; at the other side bore another hole for the glass tube which covers the platinum. At the edge of the cork cut a nick through which the air can pass when the cork is pushed into the tube.

Pass the zinc rod about 1 cm. through the cork. Carefully clean the glass tube and platinum wire, then heat the exposed end of the wire red hot, and insert it in the mercury in the test tube, taking care that the whole of the exposed platinum is covered.

Shake up the paste, and introduce it without contact with the upper part of the sides of the test tube, filling the tube above the mercury to a depth of rather more than 3 cms.

Now insert the cork and zinc rod, allowing the glass tube to pass through the hole in the cork made for it.

Push the cork gently down until its lower surface is nearly in contact with the liquid. The air will thus be nearly all expelled, and the cell should be left in this condition for at least twenty-four hours before sealing, which should be done in the following way—

Melt some marine glue until it is fluid enough to pour by its own weight into the test tube above the cork, using enough to cover completely the zinc and soldering. The glass tube should project above the top of the marine glue.

The cell thus set up may be mounted in any desirable way; do it so that the cell is immersed in a water-bath up to the level, say, of the upper surface of the cork. Its temperature can then be determined more accurately than is possible when the cell is in air.

### Instruments for Standard Measurements of the Highest Accuracy.

The potentiometer in general must rank as one of the first of this kind, not solely from the point of view of accuracy, but also because of the ease and rapidity with which the measurements possible with it can be taken. The principle underlying its use is contained in the Clark-Poggendorff method of comparing E.M.F.s, and an elementary application of this principle in Poggendorff's method of calibrating a voltmeter, a detailed description of which will be found in the author's work entitled *Practical Electrical Testing* for first and second year students. It may, however, here be remarked that when using the potentiometer for measuring current, resistance, and high voltages, the principle, as is well known, consists in reducing any of the three electrical quantities which are to be measured, to the form of electrical pressure, or E.M.F., so that it can be compared by means of a potentiometer with a standard pressure such as that of the Clark cell.

### The N.C.S. Potentiometer.

This is a somewhat new type of potentiometer, in which there is *no slide wire* to get injured or deteriorate with time. It works entirely by means of adjusted resistances of perfectly definite values, the ends of which are permanently attached to circular rows of contact studs.

Fig. 205 shows a general view of the potentiometer in its containing case with the lid slightly raised. The internal

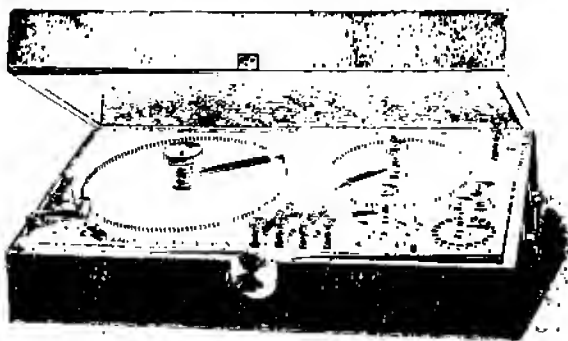


FIG. 205.

arrangements and connections are seen in the symbolical diagram, Fig. 206, with reference to which the working of the instrument will be understood more clearly. The two diagrams exactly correspond with one another so far as the relative positions of the various parts are concerned.

A secondary battery is joined to the two terminals *F*, and sends a current through the two dials *C* and *D* in series and then through adjusting resistances *K* and *H*. The *C* dial has 150 exactly equal coils in it, numbered from 0 to 150. The *D* dial has 100 equal coils in it, the whole dial being exactly equal to the one coil in *C*. The two together are therefore

equivalent to a slide wire with 15,000 fixed contacts at equal distances. The dial *K* contains nineteen equal small wire resistances, and *H* is a carbon resistance for fine adjustment of the current, so that working with one secondary cell, the potentiometer can be set to read volts direct with a Clark cell.

A standard cell of known E.M.F. is joined up to *A* + and *A* -, and the switch *L* is put over to *A*.

Any convenient galvanometer, the most convenient form being a D'Arsonval, is joined up to the galvanometer terminals.

Say the voltage of the standard cell, at the temperature used, is 1.4412; the arm of the *C* dial is then set to 144, and that of the *D* dial to 12.

The galvanometer key is then depressed on to its first stop (taking care that the catch is underneath so that it cannot go right down) and the outside resistance *K* is adjusted till—with the switch on one stop—the deflection is one way, and, with it on the next, in the opposite direction. The head *H* is then turned until an exact balance is obtained. A slight pressure should be put on the head *H* when turning it; it may not be found necessary to use *H* at all the next step.

Push aside the catch on the galvanometer key and depress fully. This cuts out a  $\frac{1}{2}$  megohm which was previously in circuit to protect the cell.

An exact balance can now be obtained by further adjustment of *H* or possibly *K*.

The instrument is now set so that each division on *C* is equal to .01 of a volt, and each division on *D* is equal to .0001 volt.

Any low E.M.F. to be measured is joined to *BB* terminals and the switch *L* set to *B*; for example, a Leclanché cell or the terminals of a low resistance for current measurement.

The galvanometer key is then again fully depressed and a balance obtained by moving *C* and *D*.

The E.M.F. between *B* and *B* is then read direct on the two dials; for example, if the reading on *C* is 83 and that on *D* is 67, the volts between *B* and *B* is .8367. Any volts higher than 1.6 have to be measured on the terminals marked volts + and -, and with the switch *L* turned to *V*. The switch *M* is then turned to any convenient multiplying power, 3, 10, 30, etc., and the readings obtained from *C* and *D* (when the balance is

obtained as before) have to be multiplied by this multiplying power; for example, if  $C$  is 103 and  $D$  26, and  $M$  is standing at 30, the volts on the terminals are  $1.0326 \times 30$  or say 30.98.

The resistances in  $H$  and  $K$  are arranged so that any voltage up to 3 volts can be used at  $P$ , thus allowing either a secondary cell or two large Leclanchés to be used; it is well to leave the battery joined up to the instrument for some ten minutes or so, so as to steady down before beginning work.

A set of coils are required to potentiometer down high voltages amounting to 300 so as to bring them within range of the dials.

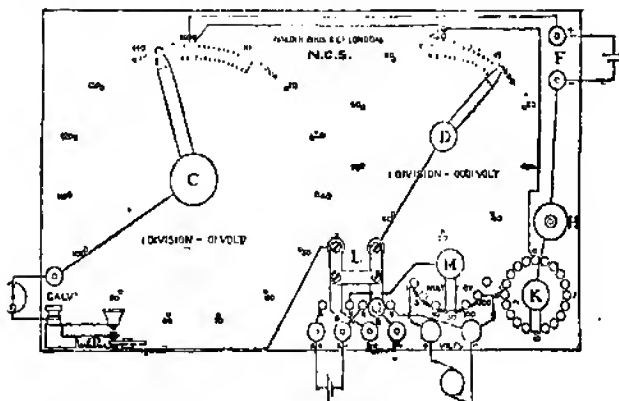


FIG. 206.

The three-way switch  $L$  according to its position inserts the known fraction of the high voltage, the standard cell, or any third unknown E.M.F. in circuit with the instrument.

The following points should be noted—

When using a standard cell, get a balance with the catch under the key before removing the catch.

Be careful to join up any coils, etc., to their right terminals and not + to -.

Do not screw the head  $H$  down too tight. It draws up a rod which compresses a carbon resistance; there is plenty of range



to cover the difference between two stops *K* without squeezing it at all tight.

Press head *H* down when turning; it keeps the resistance steadier.

The total resistance in the *M* dial is 100,000 ohms; not more than 200 volts should be applied to volts terminals for any length of time. For higher values a known resistance can be added outside and allowed for.

### Crompton's Potentiometer.

This potentiometer is shown diagrammatically in Fig. 207. It consists of a wire *AB* stretched over a scale and through which a constant current is maintained from one or more secondary cells of sufficient size to keep it fairly constant for three or four

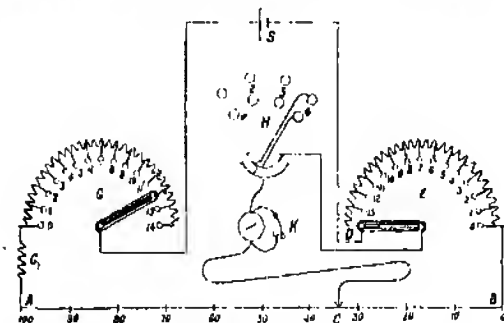


FIG. 207.

days' working. A variable resistance *G* and rheostat *G*<sub>1</sub> is introduced in series with the coil and wire, arranged so as to adjust this current to give a certain difference of potential at the two ends of the wire. The circuit which includes the E.M.F. to be measured is connected to one end *D* of the effective potentiometer wire, and through a galvanometer to a sliding saddle *C*, which carries a knife edge to make contact on the wire *AB* at any desired point of its length. This circuit is so coupled

up that the E.M.F. to be measured is *opposed* to the E.M.F. in the portion of the slide wire *BC*, in order that the position of *C* on the slide wire can be adjusted until the two E.M.F.s balance one another so that no current passes through the galvanometer. In order to compare the E.M.F. to be measured with the standard E.M.F., a Clark cell is put in in circuit with the galvanometer, and the position of the slide *C* is noted when the above-mentioned balance has been obtained. The electrical pressure or E.M.F. required to be compared is then substituted for the Clark cell, and a similar balance found by adjusting the slider *C* a second time. Then the comparison between the two E.M.F.s can be made by comparing the respective lengths of the slide wire included between the points *B* and *C* in the first and second case. By dividing the slide wire *AB* into a suitable number of parts, and adjusting the variable resistance until the galvanometer comes to zero when the Clark cell is in circuit and the contact *C* is at a point on the scale corresponding to the temperature value of the Clark cell, say 1.434 at 15°C., the instrument becomes direct reading in volts or fractions of volts.

Dr. Fleming in the year 1883 first called attention to the advantages of this system of measuring, and since that time the system has been steadily developed, and refinements have been introduced. As the following description will apply to instruments such as are suitable for a municipal standardizing laboratory, it is here necessary to specify what are the requirements and limits of accuracy within which these instruments may be reasonably expected to measure. First comes the verification of voltmeters. This is of importance on account of the disputes that are likely to arise as to the pressure supplied from electric-lighting stations. Voltmeters for standard pressures of 150 to 200 and 220 volts are principally used for noting the pressures in the consumers' houses, and for such cases it is desirable that their readings at about the standard pressure should be verified to one-tenth of a volt or within one part in 1000. Next it should be possible to verify and certify the constant of the various kinds of meters by which the electrical supply is measured to the consumers. They also ought to be verified to one part in 1000. Next comes the verification of ordinary ammeters, or current instruments used for trade

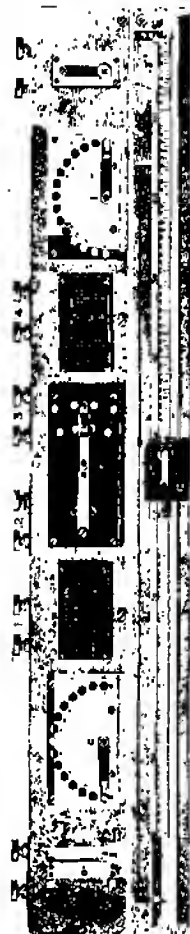


FIG. 208.

purposes to about the same degree of accuracy. In both these last cases the range through which instruments would have to be compared is very considerable; for instance, the instruments sent for verification may be those used for testing electric lamps or for telegraphic purposes, measuring currents of one milli-ampere, up to those used for metallurgical or electrolytic purposes up to 5000 amperes or more.

The correct comparison of resistance standards as well as the correctness of the ratios of resistance boxes ought to be capable of verification to one part in 10,000. In the comparison of resistances must be included the testing of the conductivity of various metals, and the insulation resistance of various insulating materials.

In the first form of instrument proposed by Dr. Fleming, the potentiometer wire was made of an alloy of platino-iridium four metres long, and had a resistance of about 23 ohms. The wire was divided into two parts and stretched over a scale; the whole of the wire, being required for measuring purposes, had to be carefully calibrated, that is to say, its electrical resistance made equal per unit length throughout its entire length. This was a very tedious and expensive process. It was found very difficult, if not impossible, to obtain wire as it finally left the drawplate, which was suffi-

ciently homogeneous to be used without further adjustment. In most cases the whole of the wire had to be carefully scraped or rubbed until the required equality of resistance was obtained. Such a wire was very valuable, and if it was broken or accidentally melted, its loss was a serious matter.

In a later form of instrument (Fig. 208) Messrs. Crompton have abandoned the use of this expensive material, and at the same time have arranged so that only one-fiftieth part of the wire *AB* is stretched over the scale and subject to the wear of working. *AB* in the drawing shows this portion of the wire 25 in. long, stretched over a scale divided into 1000 parts; therefore each division on the scale being one-fortieth of an inch, represents one fifteen-thousandth of the pressure at the two ends of the wire; in other words, if the instrument being standardized to 1.5 volts at the terminals of its wire, each of

the smallest divisions of the scale represents  $\frac{1.5}{15,000}$  or one ten-thousandth part of the volt. The resistance of this wire is usually about 2 ohms, and the remaining wire is divided into fourteen coils, each of about 2 ohms, so that the resistance of the whole is 30 ohms. These coils are naked spirals, the terminals of which are fixed to the underside of the fourteen contact blocks shown at *E*. The swinging arm shown can make contact with any one of these blocks. It is an easy matter to adjust these fourteen coils when the instrument is first made so that their resistance will accurately equal one another, and the resistance of the working wire *AB* can then be adjusted by slightly stretching it until it is also exactly equal to any of them. As the fourteen coils are protected they never need further adjustment, but if in the course of time the exposed portion of the wire *AB* becomes worn or is in any way damaged, a new piece of wire can be substituted in a few minutes and stretched by means of the stretching screw shown at *F*, until its resistance over the portion from 0 to 100 exactly balances that of any one of the fourteen coils. *C* is the sliding saddle carrying the contact. This consists of an ebonite box arranged to slide smoothly on the scale. It is provided with a knife-edge spring contact so that the contact may be made with a regular pressure which is independent of the pressure of the hand of the user; it also has a micrometer adjustment for

accurate work. The semi-circular switch *G* and the cylindrical rheostat *G*<sub>1</sub> shown to the left, which latter gives a graduation of resistance, form part of the variable resistances above described, and which are required to reduce the difference of potential between the terminals of the wire from that of the secondary cell 2 volts to any desired value. The value that has been chosen in this instrument is 1.5 volts. The instrument is provided with four pairs of terminals, 1, 2, 3, 4. A Clark cell can be put on to one of these, and any three other electrical pressures to be measured can be connected on to the others. The switching arrangement *H* shown in the centre brings the galvanometer into series circuit with any one of these pairs of terminals. The contact key *K* shown to the extreme right is used for short-circuiting the galvanometer.

Whenever it is required to measure an electrical pressure greater than that on the terminals of the potentiometer, that is to say, in this case, greater than 1.5 volts, the pressure to be measured is applied to certain terminals of a resistance box, and the terminals of the potentiometer are connected to other terminals on this box, which include between them a resistance which is an even part, say, one-tenth, one-hundredth, or one-thousandth of the entire resistance of the box.

When, however, the potentiometer is employed for measuring currents, this is done by measuring the difference of pressure at two points on standard resistances which, in order to make the instrument direct-reading, must be either 1 ohm, one-tenth, one-hundredth, or one-thousandth and so on. As these low resistances have often to carry very high currents, they have to be designed so that they do not heat to a sufficient extent to introduce errors. A description of a few different forms of them will be found on p. 601.

#### METHOD OF "SETTING POTENTIOMETER" BY STANDARD CELL.

One secondary cell being connected direct to the extreme left-hand pair of terminals, the galvanometer to those on the extreme right and a standard Clark cell to terminals *IV* suppose. Note the *temperature* of the Clark cell on its own thermometer, and from the table showing its E.M.F. for different temperatures

affixed to the instrument or by calculation, using the formula on p. 17, or *table p. 643*, obtain its present E.M.F. corresponding to its present temperature. For example, suppose this to be  $15^{\circ}\text{C}$ ., then the E.M.F. = 1.4340 volts.

Next place the double switch *H* on studs 4, the lever on stud 14 of *E*, and the slider key *C* at 340 on the scale, then pressing this latter, adjust the resistance *G* and rheostat *G*<sub>1</sub> so that the galvanometer comes back to the zero, at which it was originally set. Now every one of the scale divisions will be equal to one-tenthousandth of a volt, and the potentiometer is thus "*set*." To use the instrument for voltage measurements *H* is turned to the unknown E.M.F., while *G* and *G*<sub>1</sub> remain untouched, only *E* and *C* now being varied to obtain balance with the unknown E.M.F. in circuit with the galvanometer.

**Precautions.**—A high resistance, such as 10,000 ohms, should always be connected up in series with the standard cell before placing this across the terminals of the potentiometer, but when balance in the "*setting*" is practically obtained, the resistance can be cut out of circuit to make the balance as sensitive as possible. By doing this the cell will not be able to send any but an extremely small current when the balance is *far from perfect*, and only under such conditions of use can the cell be relied on as an accurate and constant standard of E.M.F. of the value set forth in the table above mentioned.

In taking a series of readings with a potentiometer, care should be taken, at intervals, to see that the "*setting*" with the Clark cell remains constant, and if it doesn't, to adjust so that it is.

**Sources of Error.**—The current from the secondary or "*Working cell*" through the stretched wire and resistances *E* *altering*, owing to the E.M.F. of this cell varying. To prevent this it is advisable not to use a newly-charged cell, the E.M.F. of such being liable to frequent alteration, but to use one amply large enough, that has already been  $\frac{1}{2}$  discharged. An extremely constant E.M.F. and current will then be obtained.

Again, a further error will be introduced by the stretched wire not being uniform, and great pains should be taken to ensure that it is uniform. This may be proved by calibrating it carefully in the manner employed in thus testing a metre bridge wire, a

full description of which is given in the author's work on *Practical Electrical Testing*; or by sending a perfectly steady and constant current through the wire and measuring the fall of potential down equal lengths throughout the scale.

Still another error may be caused by leakage causing the galvanometer to deflect when an accurate balance has been obtained. To avoid this, the insulating of the various pieces of apparatus should be attended to.

The above form of potentiometer has been much improved by the makers, and that made at the present time differs from the above in several constructional details. These, together with the appearance and connections of the latest type of instrument, will be easily understood from the following description by the makers.

The construction of the potentiometer itself is shown diagrammatically in Fig. 200. The calibrated wire is arranged in fourteen coils, called potentiometer coils, lettered *AB*, and a straight section *BC*, called the scale wire, the resistances of the several coils and of the straight section being equal. One sliding contact *Q* moves over the terminals of the fourteen coils, and another *R* along the straight wire. The reading of the instrument in the position shown is 1.046. The pairs of points whose potential differences are to be compared are connected to the blocks of the double-pole switch *K*, whose levers, *MN*, connect them, one pair at a time, to the sliding contacts *QR* through the galvanometer. The galvanometer key *H* is arranged to complete the circuit through two resistances, which are short-circuited in succession as the key is depressed. The current required is derived from a small secondary battery *G*. An adjustable resistance, consisting of a set of coils *DE*, and a continuous rheostat *F* is placed in the circuit. By adjusting these the resistance of the circuit and the current passing through it from the storage cell, and consequently the fall of potential along the scale wire can be continuously altered, and the operator is able to obtain a galvanometer balance against a standard cell when the reading of the sliders is that of the known E.M.F. of the cell at its actual temperature. If, for example, the temperature of the cell be 15°, so that its E.M.F. is 1.434 volts, the sliders may be set to that reading, and the galvanometer brought to zero by

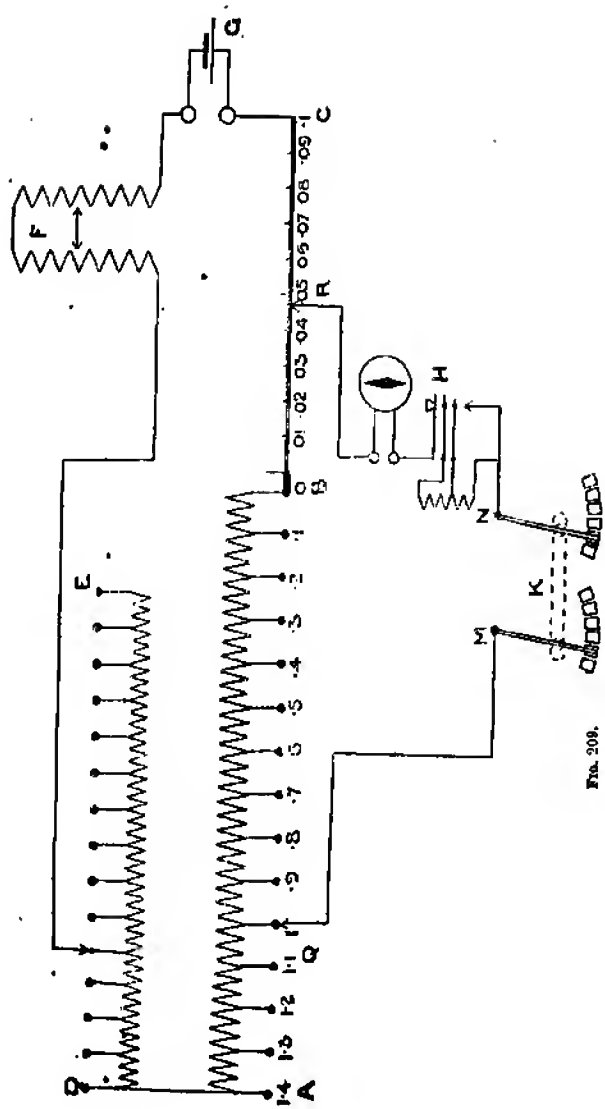


FIG. 200.



adjusting the resistance *DE* and the rheostat *F*. When this has been done the scale readings at all points are direct readings in volts.

A view of the potentiometer is given in Fig. 210, and a diagram of its internal connections in Fig. 211. Here *a b* is the scale wire; *c* the set of equal potentiometer coils in series with it; *d* is the double-pole switch connecting the six pairs of terminals *ABCDEF* in succession to the slide contacts; *e f* are the resistance coils and rheostat respectively, and *G* is the galvanometer key. All the moving contacts are under glass, and the coils and the scale wire are inside the box. The box itself is completely closed, but the inside can be inspected by removing a sliding bottom. Nearly all the measurements made, involve the use of a standard cell, and one pair of terminals, the pair *A*, is assigned to its connections to save confusion in working. Fuses of fine wire are inserted at all terminals except those for the galvanometer to save the instrument coils in the case of an accidental connection to a source of high pressure.

Two scales are engraved for slide wire readings. One is a series of even divisions from 0 to 105, the resistance of the scale wire between 0 and 100 being the same as that of each potentiometer coil. It has been found convenient to be able to take readings a little beyond the 100 mark without having to move the potentiometer coil switch, and the scale is extended to 105 to admit of this. The other scale gives the values of the Clark cell at different temperatures, and is used in the following way:—The potentiometer coil switch is set to 14, and the slide to the temperature of the Clark cell taken from the thermometer attached to it. The potentiometer reading is then the correct value in volts of the Clark cell at that temperature. By adjustment of the rheostat the galvanometer is balanced, and when this has been done the current in the potentiometer wire is such that readings at all points give correct values in volts, and the instrument is a direct-reading voltmeter. Its maximum range is then 1.5 volts, reading in thousandths of a volt, and by inspection to ten thousandths.

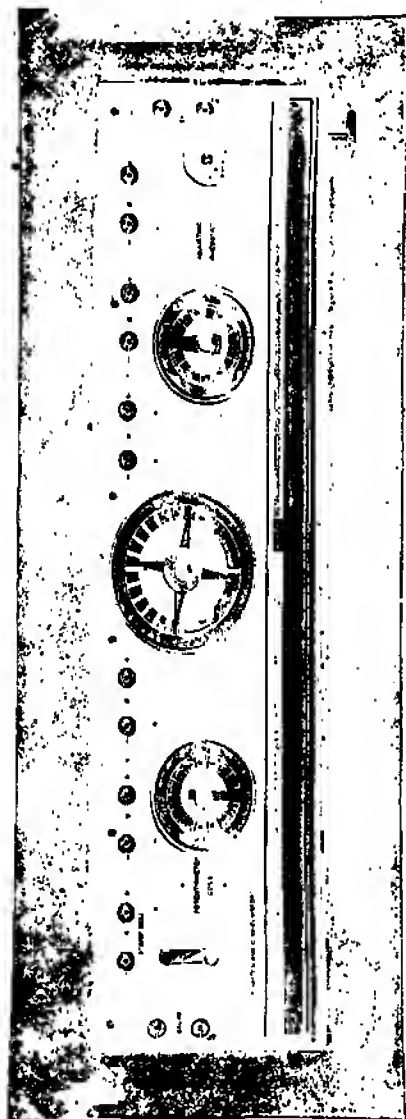


Fig. 210.



### Potentiometer Volt Box.

This is a simple and most convenient piece of apparatus by means of which a known definite fraction of any voltage can be easily and quickly obtained. Hence such an instrument can be employed with a potentiometer for the measurement of high voltages, enabling the small requisite voltage to be taken off and used for measurement in the potentiometer. Fig. 212 shows a general view and Fig. 213 (p. 523) a plan of the internal connections of a variable volt box designed by the author for use with a Crompton potentiometer. It consists of two sets of resistance coils, each set having its own separate semi-circular row of contact studs over which the spring contact levers work and make contact. Two pairs of terminals are provided, the high E.M.F. being directly connected to those marked *M*, which are larger terminals than those marked *B* to distinguish them and avoid mistakes. *B* is the side at which the known fraction of the total P.D. is obtained; and of course go to the potentiometer direct. With the levers as shown, Fig. 213,  $\frac{10}{100+100}$  or  $\frac{1}{100}$ th of the total P.D. across *M* will be taken from *B*.

### Low Resistance Measurer.

The following instrument affords a simple and convenient means of measuring very low resistances, such as are met with in the armatures of large dynamos, motors, and electric light mains. These cannot be obtained by an ordinary Wheatstone Bridge, owing to the difficulty of making, and the resistance introduced by, the contacts, and other reasons which go to vitiate and make the results worthless (see Fig. 214).

The working of the instrument is as follows—The resistance to be measured is joined in series with a battery and the slide wire. One coil of a differential galvanometer is joined by two leads to the two ends of the resistance to be measured, and the other coil across more or less of the slide wire.

The wire is divided into 1000 parts, and the whole is so arranged that the fall of potential over the whole wire, through the one galvanometer circuit, exactly balances that over  $\frac{1}{10}$  ohm in the other.

The readings are then proportional throughout the scale. By

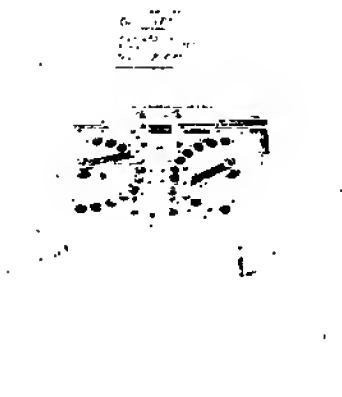


FIG. 212.

shifting two plugs the values may be multiplied by 5 or divided by 2, thus making the top read  $\frac{1}{2}$  or  $\frac{1}{20}$  of an ohm.

**Directions for use.**—Place the instrument on a fairly level table or bench.

Free the galvanometer needle by turning the screw at the back.

Turn the galvanometer on its shank till the needle points to zero.

Join the large terminals of the instrument in series with the resistance to be measured, and a cell capable of giving, say, 5 amperes; introducing somewhere in the circuit a resistance, to bring the current down to about 5 amperes.

Any odd bit of iron or German silver or other wire will do. A piece of U.S. suitable for use with a two-volt cell is sent with the instrument.

Join the long leads on to the small pair of terminals.

Depress the key on the contact arm to touch the wire; close the circuit switch, and the direction of the deflection.

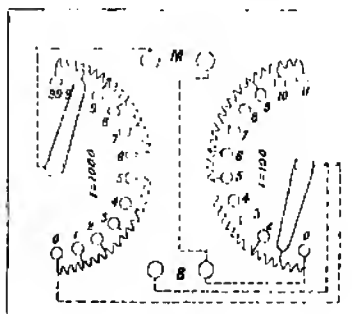


FIG. 213.

Press the two contact spears at the ends of the long leads on to the two points between which the resistance is to be measured—the contact arm being up. Again close the circuit switch and note direction of deflection. If in same direction as before, reverse the two contact spears.

Then, keeping the spears pressed on the resistance to be measured, depress the key on the contact arm.

If the deflection reverses it shows that the full of potential over  $R$  (the unknown) is less than that over the wire, and the arm must be moved back towards the zero end until the galvanometer needle points to zero.

The arrow on the contact arm then points to the resistance on

the scale direct in ten-thousandths of an ohm, thus a reading of 517 is  $\frac{517}{10000}$  or .0517.

When the plugs are in 2 and 3 the instrument reads as above described. When in 1 and 2 the reads must be multiplied by 5, thus a read of 274 =  $0274 \times 5 = .1370$  ohm. When in 1 and 3 the reads must be divided by 2, thus  $93 = .0098 \div 2 = .0049$  ohm.

The spears should make fair metallic contact, but nothing more is necessary.

The galvanometer turns on its pillar, and can thus be set to zero. It should be set to zero with the current switch closed,

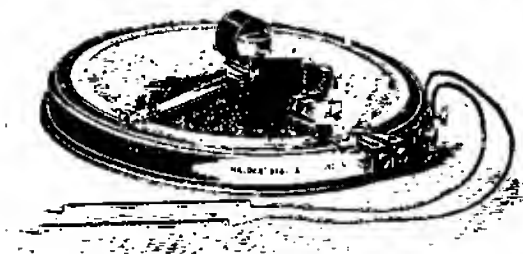


FIG. 211

but without the contact arm being pressed or the spears in contact. This avoids all disturbances from the heavy current leads.

The contacts in the current leads do not need any care, their resistance, even if variable, does not affect the result.

### Approximate Tests for very Low Resistances.

In armatures it is sometimes desirable to test each bar separately, to see that they are all the same, but if tested as above the reading would be so very small that there would be no certainty. A comparison of the bars can be taken by putting a shunt of any

convenient size, say 6" of No. 8 platinoid, across the heavy terminals *T T* at the end of the slide iron; using a larger current and working as before. The results will be of course only comparative, but if the shunt is firmly fixed, the readings will be quite sufficiently accurate for practical purposes. In the same way any two very low resistances can be compared by putting the two in series with the instrument and then transferring the point contacts from one to the other.

### Siemens Low Resistance Bridge.

**Instructions for use.**—Connect up as shown in Fig. 215, which is a symbolical representation of the bridge and its connections, the general view being shown in Fig. 216.

In each of the arms of the branch box marked *x*, unplug equal resistances and also on the  $\rightarrow$  side, the resistances being chosen according to the magnitude of the resistance to be measured.

The slide wire resistance is carefully calibrated and is compensated for all changes of the air temperature so that 0 to 100 = 0.01 standard ohm. (At any time should the wire require cleaning, only chamois leather should be used for the purpose.)

The contact slide vices, etc., are arranged for testing conductivity, but any other resistance may be tested on joining it by four connection leads to *L1, Ly* and *L2, Lz*; *L1* and *L2* being the "current connections" and *Ly* and *Lz* the "potential connections," it must be remembered that any excessive resistance in the leads from the potential contacts to the branch box would increase the value of the branches and should be allowed for; they should therefore be as low as conveniently possible. The battery used should be one of low internal resistance; the galvanometer serves to indicate that there is a current flowing in the circuit.

**Resistance Test.**—The left-hand vice, etc., being clamped at zero, insert the specimen and clamp it at both ends; the length corresponding to the resistance measured will be given by the pointer on the meter scale, and is the distance between the two knife edges or "potential contacts." Alter the position of the sliding roller contact on the resistance wire until after closing



the battery circuit by means of the key *B*, and then pressing key *M*, no motion of the galvanometer needle is observed; the

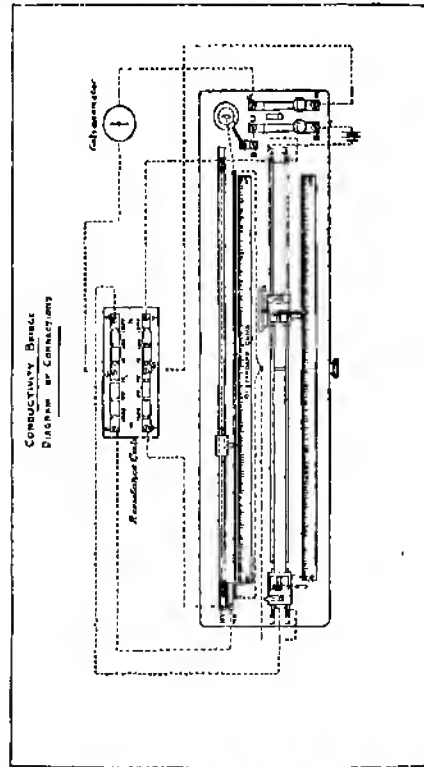


Fig. 21.

position of the roller contact being then read off, will give the resistance on the slide wire (*S*).

Then the resistance of the specimen is  $X = S \cdot \frac{x}{+}$  ohms.



FIG. 211.

**Example.**—If the two tens be unplugged on the  $\times$  side and the two thousands on the  $\div$  side and  $S = 45.5$ , then

$$X = \frac{45.5}{100} \times \frac{1000}{1000} \times 0.01 = 0.000455 \text{ standard ohm.}$$

**Conductivity Test of Copper Wire**—For determining the conductivity of copper wire, the wire where it will come in contact with the vices and knife edges must be cleaned from all oxide. Then insert the end in the left-hand vice and clamp it. The right-hand vice must now be set by the pointer opposite the temperature of the specimen, as shown by the small scale, which is graduated from  $45^{\circ}$  to  $75^{\circ}$  F. The distance between the knife edges when the pointer is opposite  $60^{\circ}$  F. is 816.06 m.m., and the scale is calculated so that the difference in length compensates for the difference of resistance due to temperature of the copper.

Proceed as before to measure the resistance ( $X$ ), taking note of the exact length in millimetres as shown by the metro scale. Then cut off by means of the knives and ascertain its weight in grammes, and by simple proportion determine the weight of 816.06 m.m. ( $W$ ). The resistance of a pure copper wire 816.06 m.m. long weighing 1 gramme is 0.1 standard ohm @  $60^{\circ}$  F.

Then the conductivity per cent. of pure copper is

$$\frac{0.1}{X \times W} \times 100.$$

**Example—**

Length cut off	Weight in grammes	Weight of 816.06 m.m.	Resistance $X$	Value of $X \times W$	$\frac{X}{\text{conductivity}}$
1.99 m.m.	14.45	14.76	0.00996	0.1027	97.88.

### Amsler's Planimeter.

If any figure on paper is measured in the ordinary way with compass and rule, the figure is first divided into triangles the area of which can be calculated, and the sum of their areas will give the area of the figure.

This method was shortened very much in 1827 by Mr. Oppenkeffer, a Swiss engineer, who invented an instrument called the "Planimeter," which measured the area of plain surfaces by following the outlines of the figure with a pointed tracer, which, being connected with a dial-plate, showed the area of the figure. This instrument soon came into general use, although somewhat awkward and expensive.

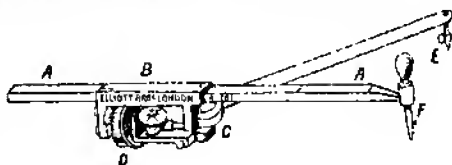


FIG. 217.

In 1849 an improvement was made by Mr. Welty, another Swiss engineer, which was still rather clumsy. No further improvement was made till 1854, when Mr. J. Amsler, Professor of Mathematics at Schaffhausen, introduced the Planimeter which is now in use; the construction is simple, the instrument can be carried about without fear of damage. One experiment showed that an area which after dividing it into triangles took nearly three hours, was done by Amsler's Planimeter in about two or three minutes.

#### INSTRUCTIONS FOR WORKING THE PLANIMETER.

(1) Before working with the instrument, adjust the screw centres upon which the index roller *D* revolves, so that the roller works freely, and does not touch the vernier. The same care must also be taken with the centre pin *C*. It is good to grease

the screw centres now and then, so that they work easily. Care should be taken to prevent the tube *B*, the tracer *F*, and the point *E* from being bent, and also to see that the barrel *D* is kept uninjured.

(2) To find the area of any figure, set the roller *D* and the counting wheel *G* to zero; the square rod *A* must be pushed into the tube *B*, and the line on *A* marked 1 sq. dem., or 0.1 sq. ft. etc., must come even with the small line on the bevelled part of the tube *B*; when this is done, place the instrument on the paper, and see that the roller *D*, the tracing point *F*, and the needle point *E* touch the paper. Press the point *F* slightly into the paper, and put the small German silver weight on the hole over the point *E*; the instrument is then ready for work.

(3) Take any point *P* on the outline of the figure about to be measured, set the tracing point *F* to that point, and when it is marked, read off the index roller *D* and counting wheel *G*. For example, suppose the counting wheel *G* shows 2, the roller *D* 91, and the vernier 5, the number will be 291.5. Follow the outline of the figure with the point *F* as accurately as possible to the right, until you come to the starting-point. Straight lines can be followed along a ruler; then read off the numbers on wheel and roller; say it is the second time 476.7.

(4) When these two numbers are obtained, there are two cases to be observed—

(1st) If the point *E* is outside the figure, subtract the first reading 291.5 from the second 476.7, the remainder is 185.2, which shows that the area contains 185.2 units. Of course the units depend entirely on the regulation of the bar *A*; if they are 0.1 sq. ft. we have  $185.2 \times 0.1 = 18.52$  sq. feet, as the area of the figure measured on the paper.

The rule therefore is, when the point *E* is outside, multiply the difference of the two readings by the number on the bar to the right of the corresponding division.

(2nd) When the point *E* is inside the figure, before making the subtraction, the number engraved on the top of bar *A*, above the corresponding line of division, must be added to the second reading. In this instance, suppose the number on top of bar *A* is 20.985, the second reading is 4.767, the calculation would be as under—

$$\begin{array}{r}
 \text{2nd reading} = 4.767 \\
 \text{Number over 0.1 sq. ft.} = 20.985 \\
 \hline
 25.752 \\
 \text{Deduct 1st reading} = 2.915 \\
 \hline
 \text{Remainder } 22.837
 \end{array}$$

The area is therefore 22.837 units or  $22.837 \times 0.1 = 2.2837$  square feet. It is of no consequence whether the roller is inside or outside the figure, provided it is on the same level.

(5) In measuring large figures, it may sometimes happen that the wheel *G* goes through one or two or more entire revolutions. If such is the case, 10,000 or 20,000, etc., must be added to the difference of the two readings before multiplication.

There is another form of planimeter which measures surfaces in square inches only; it is more simple than the other in construction, and can be worked with the above directions, always bearing in mind that the result is shown on the counting wheels in square inches and not as in the other instrument in 0.1 square decimetres, or 0.1 square feet, etc.

### Amsler's Planimeter for Determining the Mean Pressure in an Indicator Diagram.

By the use of this instrument a great saving of time is effected in calculating large numbers of indicator diagrams, and the results obtained are more accurate than by any other method.

#### DIRECTIONS FOR USING THE PLANIMETER.

The diagram is carefully pinned to a perfectly flat board. The points *OO* of the planimeter are adjusted so that the distance between them is equal to the length of the diagram projected on to the atmospheric line. The instrument is then placed upon the board, the point *b* being brought into agreement with any fixed point of the diagram, while the weighted point *c* is placed in any convenient position outside the diagram. The point *d* is then passed once round along the lines of the diagram. The indication

on the wheel *P* and disc *S*, when the point *b* has again reached the starting-point, divided by 40 gives the mean height of the diagram in inches. Supposing, for instance, that the wheel *P* was adjusted to stand at zero before using the instrument, and that, after tracing the diagram, the disc *S*—which advances by one figure for every ten revolutions of the wheel *P*—stands between 1 and 2, while the wheel *P* indicates 21·2, a vernier being provided for reading the last figure, then the resulting number is 121·2, and this divided by 40 gives 3·03, which represents the mean height of the diagram in inches. Now, supposing that the diagram was taken by means of a No. 7 Richards Indicator Spring with a scale of 32 lbs. to the inch, then the mean pressure amounts to  $3\cdot03 \times 32 = 96\cdot96$  lbs. per square inch.

In practice the calculation is somewhat simplified, as the springs used are mostly of such scales that instead of dividing by 40 and multiplying by the vertical scale, the mean pressure may be obtained by simply multiplying by a factor corresponding to the scales used.

In order to secure accurate results, the instrument must be carefully cleaned before being used, and the board must be perfectly flat.

### Thompson's Indicator.

The chief distinguishing feature of this Indicator consists in a novel parallel motion which is preferable to the motion employed in the Richards Indicator on account of its greater lightness and rigidity. The irregularities in the diagram due to the inertia of the moving parts are consequently greatly reduced, and a figure is obtained which forms the nearest possible approximation to the correct diagram. The parallel motion is carefully designed to ensure that the pencil point describes a straight line, and that the motion of the pencil point is precisely proportional to the displacement of the indicator piston throughout the stroke.

Owing to its general efficiency, this indicator is also particularly applicable for high speeds, and it has been successfully employed at a speed of 400 revolutions per minute.

The piston is rigidly connected with the piston rod, which is guided in the cylinder cover, and in this way a perfect guide is

obtained for the piston. The tension of the spring in the drum

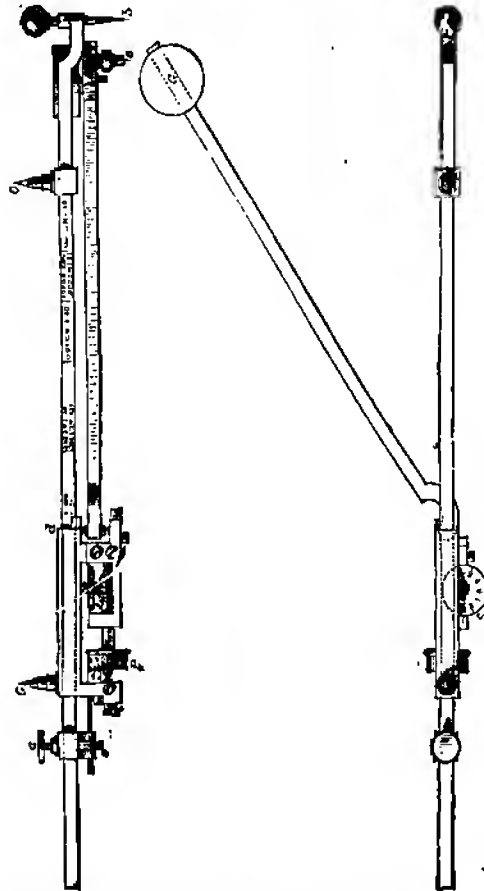


FIG. 212.

can be varied to suit the speed of the engine by loosening the

put on the top of the drum spindle and by turning the disc hold-

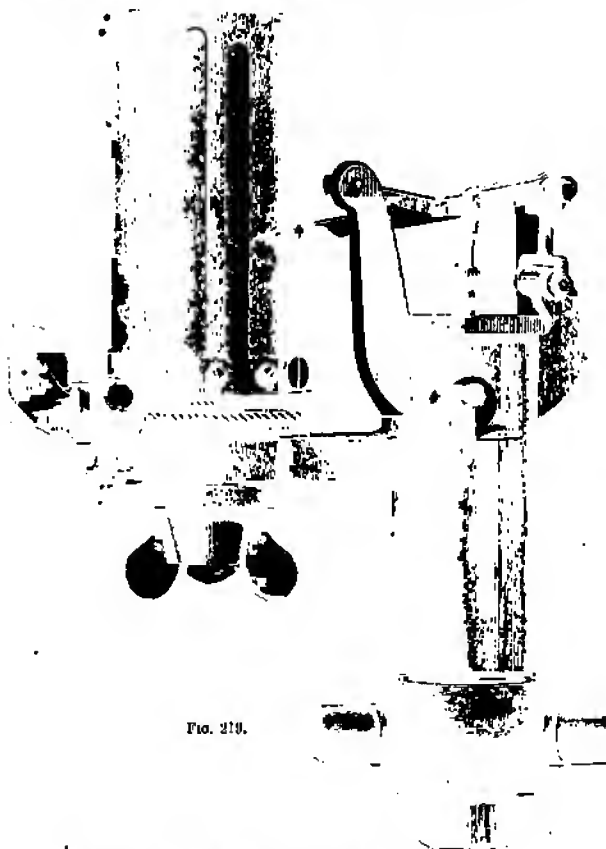


FIG. 219.

ing the spring until the required tension is obtained, the nut being then again screwed home.



TABLE VIII.

\* LIST OF SPRINGS FOR THOMPSON'S INDICATOR.\*

SIZES, No.		0	1	2	3	4	5	6	7	8	9	10	11	12
For pressure from	(Lbs. per sq. inch)	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Scale: 1 lb. per sq. inch equals		8	12	18	30	40	50	68	75	95	120	150	180	200

### Small Thompson Indicator.

This indicator is specially adapted for indicating high-speed steam engines, gas engines, etc., and will give correct diagrams at all engine speeds occurring in practice without the necessity of taking special precautions, and has the further advantage of being very portable. It is, therefore, eminently suited to the requirements of the engineer or engineering student. The apparent disadvantage of a somewhat smaller diagram obtained from this indicator at slow speeds is more than compensated for by increased accuracy.

TABLE IX.

LIST OF SPRINGS FOR THOMPSON'S SMALL INDICATOR.

SIZES, No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
For pressure from	(Lbs. per sq. inch)	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Scale: 1 lb. per sq. inch equals		8	12	20	30	45	60	70	80	100	125	150	200	250	300	375

### The Silvertown Portable Testing Set.

This is a small collection of the necessary instruments for testing electrically such insulated conductors as are used in telegraph, telephone, or electric-light work.

The whole set is contained in two small wooden boxes, of which one holds the batteries and the other the galvanometer, resistance coils, key, and commutators required for making the two most important measurements on such circuits. These are measure-

ments of the resistance of the conductor, and the efficiency of the insulation.

The battery consists of two parts: one—commonly called the

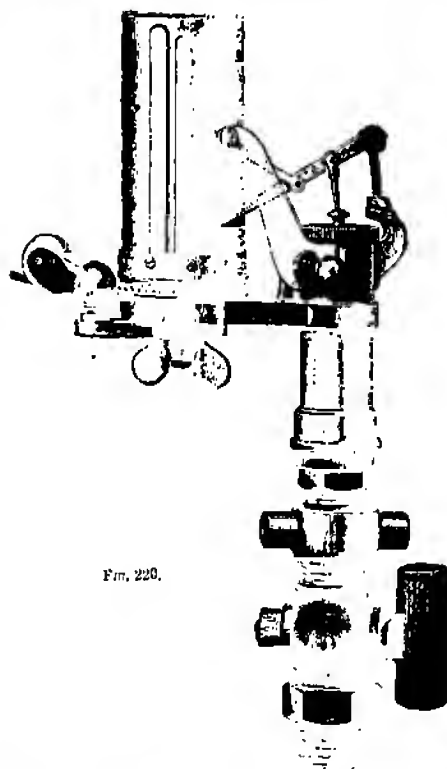


FIG. 220.

bridge battery—is a set of three Leclanché cells of low resistance intended to be used in testing conductor resistances only, a purpose for which currents of electricity of sensible magnitude are

required. The other part is a set of 36 small Leclanché cells having a total electro-motive force of 55 volts, intended exclusively for measuring insulation resistances, or other resistances, of considerable magnitude. These cells are designed to give only very small currents of electricity, and care should be taken not to connect them inadvertently to the Wheatstone Bridge or otherwise put them on a circuit of low resistance. This battery, called

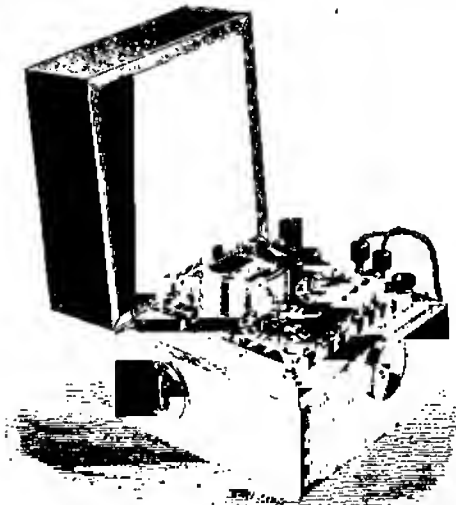


FIG. 221.

the insulation battery, is subdivided into three sections of 3, 15, and 39 cells, so that electro-motive forces of about 5, 25, or 60 volts can be employed as may be found convenient.

For connecting the battery to the testing instruments convenient leads are provided terminating in brass plugs with insulated handles for inserting in the proper plug-holes. The instruments shown in perspective in Fig. 221 are connected up together in their own box in such a way as to secure the greatest

portability and economy of space, and to enable the two tests to be taken with the greatest readiness.

A plan of this box showing the general arrangement of all the connections, resistance coils, and galvanometer is seen in Fig. 222.

The galvanometer consists of a coil of fine wire on a brass bobbin, in the centre of which a small magnetic needle with an aluminium pointer is hung in the same way as is usual in compasses. The pointer projects through the opening in the end of the coil, and the excursions of the needle are limited by the size of the opening to about  $45^\circ$  on each side of the centre. On removing the glass cover the needle on its point may be taken out by withdrawing the slide on which it is pivoted from inside the coil. The scale, which is a scale of equal currents, is approximately a scale of tangents, and is obtained empirically by calibrating the instrument. The north end of the magnetic needle points to the left-hand side of the box when it is swinging freely in its zero position.

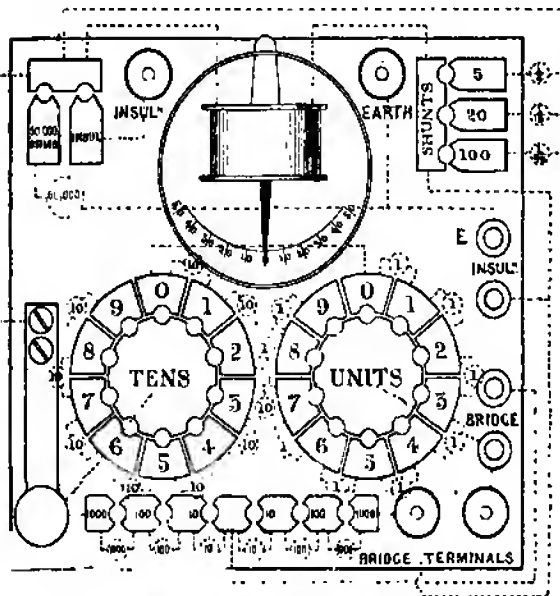
On the left-hand side of the box is placed the controlling magnet, and the position of this affects the sensitiveness of the galvanometer. When the north pole of the controlling magnet is uppermost, the galvanometer will be most sensitive; on turning the magnet round, so that the south pole is uppermost, the deflection of the needle due to any given current will be reduced by about 40 per cent. Generally in testing the insulation of well-insulated wires, the galvanometer is required to be as sensitive as possible, and the north pole of the controlling magnet should be at the top; but for measuring conductor resistances, for which the galvanometer is generally amply sensitive, it will be found more convenient to bring the south pole uppermost, thereby causing the galvanometer needle to oscillate more rapidly.

Besides thus affecting the sensitiveness of the galvanometer, the magnet is also used to adjust the needle to the zero in its position of rest by turning it slightly in one direction or the other.

The shunts shown to the right of the galvanometer are also for the purpose of diminishing its sensibility by shunting definite known fractions of the main current past the galvanometer when the plug is inserted in the desired hole.

If at any time the galvanometer needle should become insensitive and sluggish, it may be due to one of several causes, namely—

(c) That the needle has become demagnetized. This can be remedied by withdrawing and re-magnetizing it with an ordinary



General arrangement showing all connections

FIG. 222.

horse-shoe magnet, care being taken that this is done in the same direction as before.

(b) That some dirt has found its way into the jewel. This may be removed with a piece of soft wood cut to a fine point.

(c) That the jewel or the needle point is injured. In this case the slide should be removed and sent with the needle and pointer

to the makers for repair. This will probably have occurred either through the whole instrument having received a blow when the lid is open and the jewel resting on the needle point, or through the brass spring in the lid of the box being bent so that it no longer presses on the lifter when the lid is closed, and the needle has consequently been resting on the point while the box has been carried about.

The remainder of the box consists of the two-way plug switch on the left of the galvanometer, by means of which either a known standard or unknown high resistance can be separately inserted in series with the galvanometer.

The spring tapping key seen on the left hand lower corner of the box is for closing the galvanometer circuit when ordinary resistance other than that of insulation is being measured.

The two circular dials, marked *TEXS* and *XXIXS*, form the adjustable resistance arm of the Wheatstone Bridge arrangement, and consist of two sets of 9 coils each, totalling 99 ohms when both plugs are in the "9" holes, 0 when both plugs are in the "0" holes, and infinity when both plugs are out altogether.

A double set of proportional coils or resistances, each consisting of 10, 100, and 1000 ohms coils, completes the bridge. These are connected to the row of blocks seen at the bottom of Fig. 222.

The terminals shown are for connecting the battery and unknown resistance to.

### Evershed "Megger" and "Bridge-Megger" Testing Sets.

**The "Megger" Insulation Set.**—The general principle underlying the construction, as well as the internal connections, of this set will be seen by a reference to Fig. 223. As seen, the instrument is a combination of a magneto-generator on the right-hand side, with the ohmmeter portion on the left, in a somewhat unique form of magnetic circuit, common to both and consisting of two pairs of field poles braced by strong bar magnets *NS, NS*, and forming two bi-polar field magnets in series. In the right-

hand one, and rotated by a folding handle and spur gearing *D*, is the armature of the generator with its brush gear *B*, and terminal bars marked + and -. In the left-hand field is the current coil *A*, pressure coil *P*, and compensating coil *C* of the ohmmeter, connected to resistances *Q* and *R*, a "guard plate" *G*, and the only two external terminals *L* and *E* (marked Line and

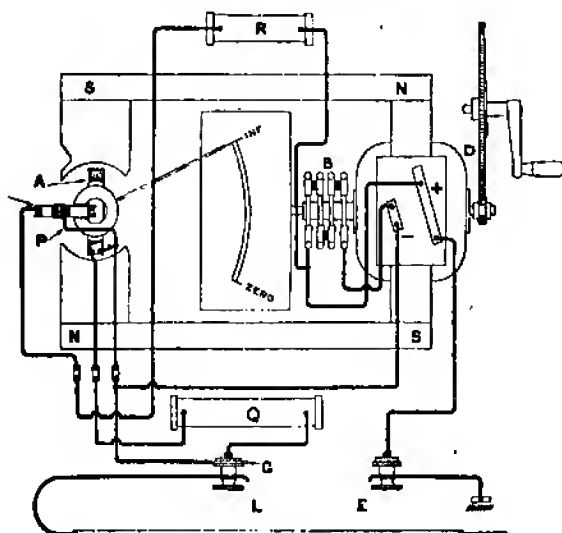


FIG. 223.

Earth in Fig. 224), which shows the general view of this set ready for use, with one end of the carrying strap detached from its spring cleat, the scale lid lifted and driving handle unfolded ready for use.

The arrangement and connections of the moving coil system of the ohmmeter of this set are shown in Fig. 229, and that of the generator armature in Fig. 231, the coils of which are numbered consecutively in order of their winding, No. 1 being

next to the core. The generator of this set may be either of the variable or constant-pressure type.

The "Bridge-Megger" Testing Set is available for use both as an insulation testing set and as a specialized Wheatstone



FIG. 224.

bridge. It differs from the above set in outward appearance only by the addition of two pairs of terminals at the left hand end, and of two switches near the top right-hand corner, as will

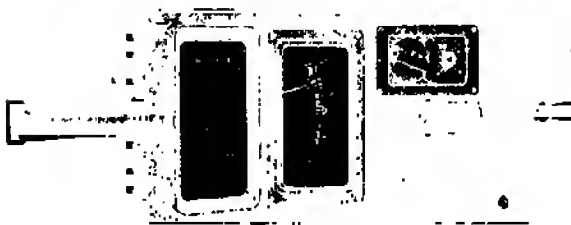


FIG. 225.

be seen by Fig. 225, showing a plan photograph of the box containing the ohmmeter and generator.

One of the two switches is a *Ratio Switch* for varying the proportion of the two ratio arms, when the instrument is used as a Wheatstone bridge, so as to make the unknown resistance ( $X$ )



under test either *equal to*, or  $\frac{1}{10}$ th, or  $\frac{1}{100}$ th of that of the standard resistance box  $R$ , thus providing a wide range of measurement which can be again increased by merely *interchanging* positions of the standard  $R$  and unknown resistances  $X$  relatively to the two pairs of terminals at the end (as seen in Figs. 44 and 45), which gives the unknown ( $X$ ) now in terms of  $R \times 10$  (or  $\times 100$ ) according to the ratio employed.

The other, or *two-way change-over switch*, when set to "*Megger*," prepares the instrument for measuring large metallic resistance

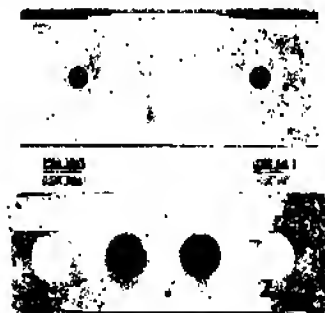


FIG. 220.

(vide p. 118), though principally insulation resistance, by coupling the two windings of the constant-pressure generator in series and making the two front terminals, marked *Line* and *Earth*, the only two available for connection.

When set to "*Bridge*," the instrument is converted for Wheatstone bridge work—the two windings of the generator being now coupled in parallel in order to increase the current obtainable from it; the ohmmeter part being changed into a galvanometer for the bridge; and the arms of the bridge being switched into their appropriate places in circuit and connected to the only available terminals (namely, the two pairs marked  $R$  and  $X$  at the end) for use now on the instrument.

The variable standard direct-reading resistance box ( $R$ ) for use in bridge measurements is shown in plan, Fig. 226, and is of

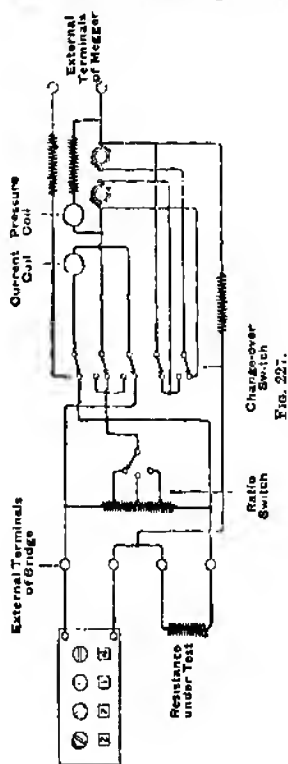


Fig. 227.

the sliding-contact type, operated by turning chronite handles. The figure appearing for each position of any handle is the resistance of that dial, and the total shown in Fig. 226 is 8,306 ohms.

The complete internal connections of a "Bridge-Megger" set

with change-over switch set to "Bridge" are given in Fig. 227, while the connections forming the usual bridge circuits are depicted in Fig. 228.

The connections of the moving-coil systems are shown separately for the "Megger" set, Fig. 229—and "Bridge-Megger" set, Fig. 230—while the armature connections of the generator are shown for these sets respectively in Figs. 231 and 232.

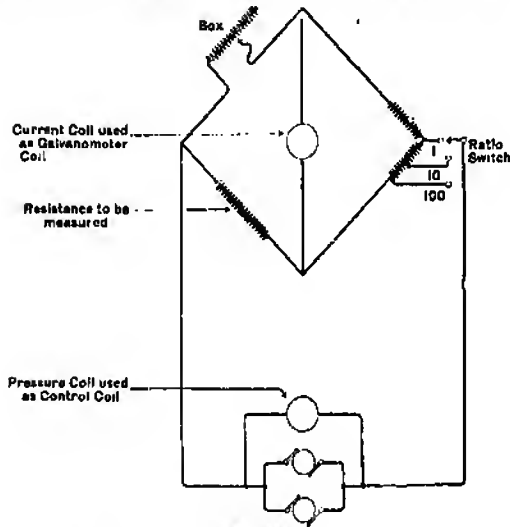


FIG. 228.

The Constant Pressure Generator for the "Bridge-Megger" set is shown in Fig. 233, the permanent bar magnets *NS* of Fig. 223 being removed for clearness.

The free-wheel attachment prevents the armature and gearing being damaged by any sudden stopping of the folding handle, and permits the armature to be driven in one direction only. Between the armature and gearing is interposed a centrifugal friction clutch comprising a drum driven by gearing, on which two arms, attached to the armature and fitted with pads at their

ends, are urged by springs. When the driving handle is turned above slipping speed, the speed of the armature, and hence its E.M.F., is extremely constant—varying as little as 1 part in 1000.

The *Index Adjuster*, fitted to the latest constant-pressure sets, consists of a small piece of soft iron rod, mounted parallel



FIG. 229.

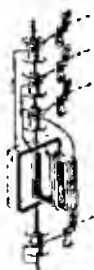


FIG. 230.

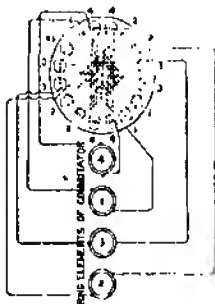


FIG. 231.

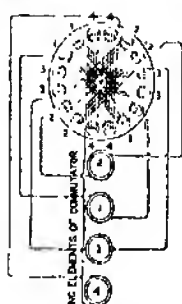


FIG. 232.

to the line joining the centres of the field poles and close to the moving coil *C*, Fig. 223. It is capable of being moved sideways in one direction or the other (relatively to *C*) by means of a knob.

The rod becoming magnetized inductively by the polar field causes some of its field to pass through the coil *C*, and hence, if the rod is moved, its field also moves slightly, which at the "infinity" position of the moving systems causes a slight deflec-

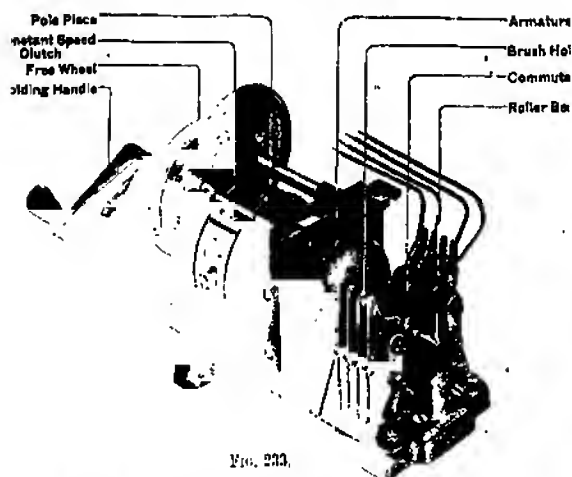


FIG. 233.

tion of the pointer one way or the other, facilitating accurate adjustment to infinity.

The adjustment does not affect the law of the instrument, which is altered only by the centre coil  $P$ .

### Standard Direct-Reading Electric Balance.

Fig. 235 shows the general appearance (with glass cover removed), and Fig. 234 a part symbolical elevation of Lord Kelvin's centi-ampere balance.



FIG. 234.

(1) The instrument is founded on the principle of action of the mutual forces, discovered by Ampere, between movable and

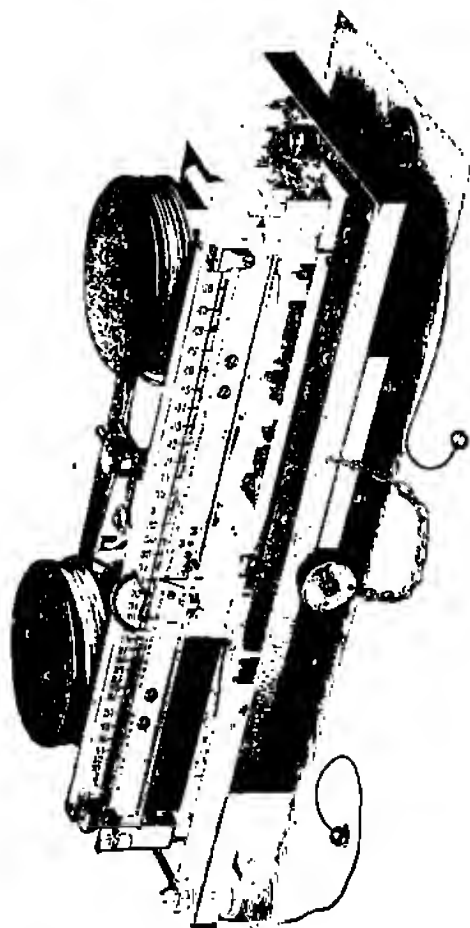


FIG. 235.

fixed portions of an electric circuit. The shape chosen for the mutually influencing portions is circular, and each such part will be called for brevity an ampere ring, whether it consists of only one turn or of any number of turns of the conductor.

(2) In this balance, each movable ring, *B* and *B'*, is actuated by two fixed rings, *AC* and *AC'*—all three approximately horizontal. There are two such groups of three rings—two movable rings attached to the two ends of a horizontal balance arm pulled, one of them up and the other down, by a pair of fixed rings in its neighbourhood. The current is in opposite directions through the two movable rings to practically annul disturbance due to horizontal components of terrestrial or local magnetic forces.

(3) The balance arm is supported by two trunnions, each hung by an elastic ligament of fine wire *f*, through which the current passes into and out of the circuit of the movable rings.

(4) The mid-range position of each movable ring is in the horizontal plane nearly midway between the two fixed rings which act on it.

(5) The current goes in opposite directions through the two fixed rings, so that the movable ring is attracted by one of the fixed rings and repelled by the other. The position of the movable ring, equi-distant from the two fixed rings, is a position of minimum force, and the sighted position, for the sake of stability, is above it at one end of the beam and below it at the other, in each case being nearer to the repelling than to the attracting ring by such an amount as to give about  $\frac{1}{2}$  per cent. more than the minimum force.

(6) The balancing is performed by means of a weight which slides on an approximately horizontal graduated arm attached to the balance; and there is a trough *t*, fixed on the right-hand end of the balance, into which a proper counterpoise weight *W* is placed, according to the particular one of the sliding weights in use at any time (sect. 9 below). For the fine adjustment of the zero a small metal flag is provided, as in an ordinary chemical balance. This flag is actuated by a fork having a handle below the case outside, as shown at the bottom of Fig. 236. To set the zero the left-hand weight is placed with its pointer at the zero of the scale, and the flag is turned to one side or the other until it

is found that, with no current going through the rings, the balance rests in its sighted position.

(7) *To measure a current* the weight is slipped along the scale until the balance rests in its sighted position. The strength of the current is then read off approximately on the fixed scale (called the inspectional scale), with aid of the finely divided scale for more minute accuracy, according to the explanations given in sect. 11 below. Each number on the inspectional scale is twice the square root of the corresponding number on the fine scale of equal divisions.

(8) The slipping of the weight into its proper position is performed by means of a self-releasing pendant, hanging from a hook carried by a sliding platform, which is pulled in the two directions by two silk threads passing through holes to the outside of the glass case.

(9) Four pairs of weights (sliding and counterpoise), of which the *slodge or carriage* and its *counterpoise* constitute the first pair, are supplied with the instrument. These weights are adjusted in the ratios of 1:4:16:64, so that each pair gives a round number of amperes, or half-amperes, or quarter-amperes, or of decimal sub-divisions or multiples of these magnitudes of current, on the inspectional scale.

(10) The useful range of each instrument is from 1 to 100 of the smallest current for which its sensibility suffices. The range of this instrument is from 1 to 100 centi-amperes. The following table shows the value per division of the inspectional scale corresponding to each of the four pairs of weights—

	Centi-amperes per division.
First pair of Weights. . . . .	0.25
Second „ . . . . .	0.50
Third „ . . . . .	1.0
Fourth „ . . . . .	2.0

(11) The fixed inspectional scale shows, approximately enough for most purposes, the strength of the current; the notches in the top of the platinum scale show the precise position of the weight corresponding to each of the numbered divisions on the fixed scale, which practically annuls error of parallax due to the



position of the eye. When the pointer is not exactly below one of the notches corresponding to integral divisions of the inspectional scale, the proportion of the space on each side to the space between two divisions may be estimated inspectionally with accuracy enough for almost all practical purposes. Thus we may readily read off 34.2 or 34.7 by estimation with little chance of being wrong by 1 in the decimal place. But when the utmost accuracy is required, the reading on the fine scale of equal divisions must be taken, and the strength of current calculated by aid of the table of double square roots given at the end of this book. Thus, for example, if the reading is 292, we find 34.18, or say 34.2, as the true scale reading for strength of current; or, again, if the balancing position of the pointer be 301 on the fine scale, we find 34.70 as the true reading of the inspectional scale.

(12) The centi-ampere balance, with a thermometer to test the temperature of its ampere rings, and with platinoid resistances up to 1600 ohms, serves to measure potentials of from 10 volts to 400 volts, and up to 2000 volts with specially constructed high resistances.

TABLE N.

CONSTANT OF THE CENTI-AMPERE BALANCE WHEN USED AS A VOLTMETER.

Weight used.	Resistance in circuit. <sup>1</sup>	Volts per division of fixed scale.
First Pair of Weights ... ..	400	1.0
" " " " " " " " " "	800	2.0
" " " " " " " " " "	1200	3.0
" " " " " " " " " "	1600	4.0

<sup>1</sup> Including resistance of the instrument, which is about 60 ohms.

If the second pair of weights is used, the constants will be double of those noted above.

(13) Instructions for the Adjustment of the Standard Balances.—The instrument should be levelled in accordance with the indications of the attached spirit level, by means of the levelling screws on which the sole-plate of the instrument stands.

(14) In this centi-ampere balance, the beam can be lifted off its supporting ligaments by turning a handle attached to a shaft

passing under the sole-plate of the instrument. This shaft carries an eccentric, on the edge of which rests the lower end of a vertical rod, which is fixed at its upper end to a tripod lifter. When the instrument is to be packed for carriage, or when it is to be removed by hand from place to place, the lifter should be raised; but when it is fixed up for regular use, it is advisable to keep the beam always hanging on the ligaments.

(15) The carriage is fitted with an index to point to the movable scale, and is intended to remain always on the rail. One or other of the weights is to be placed on the carriage in such a way that the small hole and slot in the weight pass over the conical pins. The weights are moved by means of a slider, which slides on a rail fixed to the sole-plate of the instrument, and carries a pendant with a vertical arm intended to pass up through the rectangular recess in the front of the weight and carriage. The slider and weight are shown in position in the figures. The slider is moved by silk cords, which pass out at the ends of the glass case. When the cords are not being pulled for shifting the weight, their ends should be left free so that the pendant may hang clear of the weight. When a weight is to be placed on or removed from the carriage, the slider should be drawn forward at the top until it is clear of the weight, and then pushed to one side until the weight is adjusted, when it may be replaced in position in a similar manner.

(16) Cylindrical counterpoise weights with a cross-bar passed through them are supplied for the purpose of balancing the sliding weights when they are placed at the zero of the scale. The sliding weight should be placed so that the index of the carriage points to the zero of the scale, and the proper counterpoise weight should be placed in the trough, fixed to the right-hand end of the beam, with its cross-bar passing through the hole in the bottom of the trough. The flug which is attached to the cross-trunnion of the beam should then be turned by means of the handle projecting from under the sole-plate, until the index on the end of the movable scale points to the middle one of the five black lines on the fixed scale opposite to it. *Care must be taken when making this adjustment that the fork which moves the flag is not left in contact with it, as this would impede the free swing of the beam.* The fork should be turned back a little after

each adjustment of the flag, and, when the flag is being adjusted, it is better to watch the flag itself, and make successive small adjustments until the beam stands at zero, than to make successive trials by pushing round the handle while watching the position of the index.

If the ligament has stretched since the instrument was standardized, the index at one end of the movable scale will be found to be below the middle line on its vertical scale, when the index at the other end is correctly pointing to the zero position. The error so introduced would be a small one, but it may be easily put right by slightly loosening the screws fixing the pillared frame, which supports the movable beam, to the base plate, and raising it by slipping one or two thicknesses of paper below it until the indices simultaneously point to their zero position.

(17) A lens is supplied with each instrument for facilitating accurate observation, either when reading the position of the weight or when adjusting the zero.

(18) The vibrations of the beam may be checked so as to facilitate reading by bringing the pendulum, which moves the weight, lightly into contact with it, in such a way as to give a little friction without moving the weights.

(19) In using the centi-ampere balance as a voltmeter when great accuracy is required, care must be taken that the effect of change of temperature in changing the resistance of the coils of the instrument, and of the external resistance coils, is allowed for; and in this use of the instrument it is advisable to employ currents such as can be measured by the lightest weight on the beam. When the instrument is to be used as a voltmeter, four resistances are provided, three of which are each 400 ohms, and the fourth is less than 400 ohms by the resistance of the coils of the instrument at a certain specified temperature. The smallest resistance is intended to be included by itself in the circuit when the lowest potentials are being measured, and in series with one or more of the others when the potential is so high as to give a stronger current than can be measured with the lightest weight on the beam. The correction for temperature is, for the copper coils of the balance, about 0.38 per cent. per degree Centigrade, and for the platinumoid resistances, about 0.024 per cent. per degree Centigrade.

### Anti-Inductive Resistance for the Kelvin Standard Electric Balances.

When a balance of the above type, such as, for instance, the *centi-amperes* or *composite* instrument, is to be used as a voltmeter, four resistances are provided, three of which are each 400 ohms, and the fourth is less than 400 ohms by the resistance of the coils of the balance at a certain specified temperature. These resistances are doubly wound so as to be non-inductive, and are made of platinoid wire, wound on suitable frames, so as to pre-



FIG. 236.

sent a maximum amount of cooling surface. The frames are enclosed in a box with apertures at the top to allow of the warm air getting out. Fig. 236 represents such a box for use with a Kelvin standard balance. The smallest resistance is intended to be included by itself in the circuit when the lowest potentials are being measured, and in series with one or more of the others, when the potential is so high as to give a stronger current than can be measured with the highest weight on the beam. The correction for temperature is, for these anti-inductive platinoid resistances, about 0.021% per degree Centigrade.

each adjustment of the flag, and, when the flag is being adjusted, it is better to watch the flag itself, and make successive small adjustments until the beam stands at zero, than to make successive trials by pushing round the handle while watching the position of the index.

If the ligament has stretched since the instrument was standardized, the index at one end of the movable scale will be found to be below the middle line on its vertical scale, when the index at the other end is correctly pointing to the zero position. The error so introduced would be a small one, but it may be easily put right by slightly loosening the screws fixing the pillared frame, which supports the movable beam, to the base plate, and raising it by slipping one or two thicknesses of paper below it until the indices simultaneously point to their zero position.

(17) A lens is supplied with each instrument for facilitating accurate observation, either when reading the position of the weight or when adjusting the zero.

(18) The vibrations of the beam may be checked so as to facilitate reading by bringing the plummet, which moves the weight, lightly into contact with it, in such a way as to give a little friction without moving the weights.

(19) In using the centi-amperes balance as a voltmeter when great accuracy is required, care must be taken that the effect of change of temperature in changing the resistance of the coils of the instrument, and of the external resistance coils, is allowed for; and in this use of the instrument it is advisable to employ currents such as can be measured by the lightest weight on the beam. When the instrument is to be used as a voltmeter, four resistances are provided, three of which are each 400 ohms, and the fourth is less than 400 ohms by the resistance of the coils of the instrument at a certain specified temperature. The smallest resistance is intended to be included by itself in the circuit when the lowest potentials are being measured, and in series with one or more of the others when the potential is so high as to give a stronger current than can be measured with the lightest weight on the beam. The correction for temperature is, for the copper coils of the balance, about 0.38 per cent. per degree Centigrade, and for the platinumoid resistances, about 0.024 per cent. per degree Centigrade.

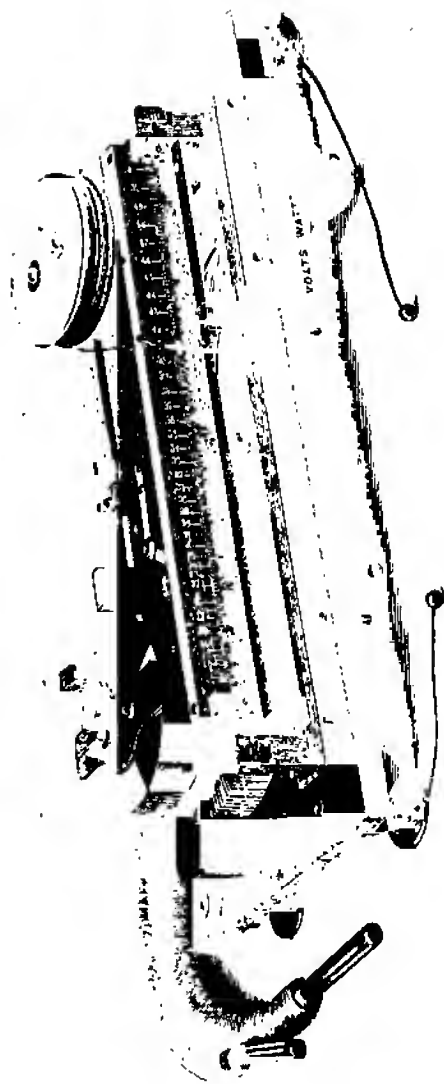


FIG. 237.

**CONSTANT OF COMPOSITE BALANCE WHEN USED AS A CENTI-AMPERE BALANCE.**

Weight used.	Centi-amperes per Division of Fixed Scale.
Sledge + $VW_1$ . . . . .	0.5
" + $VW_2$ . . . . .	1.0
" + $VW_3$ . . . . .	2.0

The volts on the terminals are calculated from the current in amperes and the resistance in ohms (including the anti-inductive resistance, if any) in circuit. If  $V$  be volts,  $C$  current, and  $R$  resistance,

$$V = CR.$$

The anti-inductive resistance is arranged so that the instrument reads a round number of volts per division.

TABLE XI.

**CONSTANT OF COMPOSITE BALANCE WHEN USED AS A VOLTMETER.**

Weight used.	Resistance in Circuit. <sup>1</sup>	Volts per Division of Fixed Scale.
Sledge + $VW_1$ . . . . .	200 . . . . .	1.0
" " . . . . .	400 . . . . .	2.0
" " . . . . .	800 . . . . .	4.0

<sup>1</sup> Including the resistance of the instrument, which is about 30 ohms.

If the second pair of weights (Sledge +  $VW_2$ ) be used the constants will be double of those noted above.

(5) To use the instrument as a hekto ampere meter the switch is turned to "Watt" and the thick wire coils inserted in the current circuit in such a way that the right-hand end of the beam is repelled up. Either the sledge alone or the weight marked  $WW$  is to be used in this case. A measured current is then passed through the suspended coils, and the constants given in the certificate for the balance used in this way are calculated on the assumption that this current is, as there stated, 0.25 ampere, but any other current which is convenient in the circumstances may be used. The current through the suspended coils may be measured by means of the instrument itself arranged for the measurement of volts. This may be done by first mea-

measuring the current which the difference of potential between the supply conductors of an electrical installation, or between the poles of a battery, causes to flow through the coils of the instrument and its external resistance, and then turning the switch to "Watt," and at the same time introducing a resistance into the circuit equal to the resistance of the fixed coils.

CONSTANT OF COMPOSITE BALANCE WHEN USED AS A HERTZ-AMPERE BALANCE.

Weight used.	Amperes per Division of Movable Scale. <sup>1</sup>
Standard + $WH_1$ . . . .	0.250
" + $WH_2$ . . . .	0.500
" + $WH_3$ . . . .	1.000

<sup>1</sup> With 0.25 ampere through movable coils.

N.B.—The constants vary inversely as the current through the fine wire coils.

(5) To use the instrument as a Wattmeter, one terminal of the fine wire coils is joined to one end of the anti-inductive resistance and the other terminal to one of the leads; the other end of the resistance being joined to the other lead. The thick wire coils are inserted in the main circuit as described in sect. 5 above. With the instrument thus joined up, the current through the suspended coils and the E.M.F. between the leads may be obtained by the operations described in sect. 4 above, since the presence of the thick wire coil in the circuit causes no appreciable error; or the E.M.F. may be taken from the electrostatic voltmeter used on the circuit, and from its indications the current in the suspended coil circuit calculated. The watts are then to be calculated from the E.M.F. on the leads and the current through the thick wire coils by the formula

$$W = VC = cCR,$$

where  $c$  is the current in the suspended coil circuit,  $C$  the current in the thick wire coils, and  $R$  the resistance in the circuit.

The weights sent out with the instrument are arranged to give a round number of Watts per division of the scale with a known anti-inductive resistance in series with the fine wire movable coils.



TABLE XII.  
CONSTANT OF COMPOSITE BALANCE WHEN USED AS A WATTMETER.

Weight used.	Resistance in Circuit with Movable Coils. <sup>1</sup>	Watts per Division of Movable Scale.
Sledge + $WV_1$ . . .	200 . . .	12.5
" " . . .	400 . . .	25.0
" " . . .	800 . . .	50.0
" + $WV_2$ . . .	200 . . .	25.0
" " . . .	400 . . .	50.0
" " . . .	800 . . .	100.0
" + $WV_3$ . . .	200 . . .	50.0
" " . . .	400 . . .	100.0
" " . . .	800 . . .	200.0

<sup>1</sup> Including resistance of movable coils, which is about 12 ohms.

### Adjustable Magneto-static Current Meter.

(1) The magneto-static current meter (Fig. 238) consists essentially of a small steel magnet or system of magnets suspended in the centre of a uniform field of force due to two coils, each having one or more turns of copper ribbon or wire, and also under the directive influence of two systems of powerful steel magnets.

(2) The suspended system of magnets is attached to one end of a vertical shaft passing down centrally through an opening in the sole-plate of the instrument from an indicating needle, which is supported by a jewelled cap resting upon an iridium point.

(3) The two systems of directive magnets are circular in form, and each ring is composed of two semicircular magnets placed in a brass cylindrical frame with their similar poles together. Each system is securely fixed to a circular brass frame, which fits on to the cylindrical case of the instrument in such a manner that the systems are capable of being turned round, together or separately, as explained below.

(4) The instrument has a "tangent scale," which is adjusted in its position before the instrument is sent out, so that the needle indicates equal differences of readings for equal differences of current. The scale consists of a hundred divisions, and for most purposes it is convenient to set the field magnets in such a position

that the needle points to 0, and to use the scale from that point upwards towards 100. Sometimes, however, it may be found convenient to measure currents, whose direction is being occasionally reversed, without being at the trouble of reversing the electrodes in the contact clip; in that case the zero should be set to the division 50 at the middle of the scale, and readings taken on each side of it. It must be remembered that when the point taken as zero is changed, the *constant*, by which the indications of the instrument have to be multiplied to give the current in amperes, is changed in proportion to the cosine of the angle between the zero point and the middle of the scale; and as this



FIG. 218.

angle is  $60^\circ$ , the *constant* with the zero at 50 on the scale is exactly double the *constant* with the zero at 0 on the scale.

(5) The instrument is provided with a "lifter," which serves to raise the needle off the iridium point when it is being moved about from place to place. This lifter is in the form of a ring placed below the needle, and may be raised or lowered by turning the handle attached to an eccentric passing through the side of the instrument on a level with the scale. It also serves as a checker, by bringing it lightly into contact with the pointer, so as to stop its vibrations.

(6) The instrument has an advantage, important for some practical purposes, of being available as an accurate direct-reading

current meter, through a continuous range of from 1 to 100 times its smallest current, which may be anything from half a milli-ampere to 4 amps., according to the number of turns in the coils supplied with the instrument. It is not, however, available as an alternate current instrument, and it must be remembered that the magnetism of the steel directing magnet does not remain *absolutely* constant. With good quality of steel, a proper preliminary *aging* of the magnet (by heating it several times in boiling water and cooling it again, and subjecting it to somewhat varied rough usage) brings it to a condition in which its magnetism is found to remain exceedingly nearly constant month after month and year after year. Still, it should never be relied upon as *absolutely* constant, and for accurate laboratory work it is therefore necessary to occasionally standardize it.

(7) Another advantage which the instrument has is that, when a standard instrument is available, its constant is capable of being varied to any desired value down to one-tenth of that which it has with its directive magnets in their strongest position. Thus if the constant should be 3 amps. per division of the scale, with the similar poles of the magnets coinciding, it may be adjusted to any value down to 0.3 amp. per division.

(8) **Instructions for Use of the Magneto-static Current Meters.**—The instrument should be levelled, in accordance with the attached spirit-level, by means of the levelling screws.

(9) *To Adjust the Pointer to Zero.*—(a) Loosen the two lower milled-headed screws clamping the magnet frame, and turn the frame round till the pointer stands at zero. (b) Reclamp the frame by tightening the two screws.

(10) *Adjustment of the Scale.*—The scale, as stated above (sect. 4), is firmly clamped in its place before sending the instrument out, and this position is marked by two lines on the outside of the case, one horizontal and the other vertical, just below the 0 of the scale. The horizontal line is engraved below the movable top of the instrument, and the vertical one on the side of the case. Should the top of the instrument have been inadvertently moved, and the scale thus put out of adjustment, it may be set right by slightly loosening the two slotted screws and turning the top round till the extremities of the two lines coincide.

(11) If the needle should by accident be slightly bent,<sup>1</sup> and so render a new adjustment of the scale necessary, this may readily be made in the following manner :—Set the zero, by the field magnets, to the division 50 at the middle of the scale, then join the instrument in series with another current instrument of convenient form, and pass a current through both sufficient to give a deflection of about 40 divisions on the magneto-static instrument; reverse the current on the magneto-static instrument only, and set the scale so that equal deflections, read in divisions, are given on each side of the zero for equal currents, as indicated on the auxiliary instrument. The zero must, of course, be reset by the magnets every time the scale is moved. When the scale has been adjusted to this position, firmly clamp the top of the instrument by the two slotted screws, and again mark the position of the horizontal line on the outside of the case.

(12) *Adjustment of Constant.*—The constant may be quickly varied as follows :—Join the instrument in series with any reliable current instrument of known accuracy, such as the deci-ampere balance, and pass a convenient current through both instruments, observing the readings. Break the current, loosen the two upper pairs of milled-headed screws, and turn the top system of magnets relatively to the lower, so that the similar poles of the two systems are brought closer together or moved further apart, according as it is desired to make the instrument respectively less or more sensitive. Reclamp the screws and adjust the zero as described in sect. 10. Again make the current, and note the reading on the two instruments. The desired reading on the magneto-static may be obtained quickly after one or two approximations, care being always taken to readjust the zero after each movement of the top magnets.

(13) When convenient it is always best to standardize the instrument in the place where it is to be used; but when it is intended to move it from place to place, it should be standardized in such a position that when the needle is pointing to zero it is in a direction approximately east and west.

<sup>1</sup> If it is bent so largely as to be perceptible to the eye, it ought to be straightened by hand as nearly as may be.

### Electrostatic Voltmeters.

These voltmeters have the great advantage of being available as accurate measurers of potential on direct and alternating systems, and, being electrostatic, they use no current, and consequently require no temperature correction. They are therefore free from the causes of error so prevalent in instruments of the electro-magnetic type, whose accuracy is impaired by variations of temperature, and which when used on alternating systems are affected by errors due to self-induction ranging with the period of alternation.

The instruments are made on the principle of an air condenser, having one of its parts movable about an axis, so as to increase or diminish the capacity. The condenser is enclosed in a metal case, for the double purpose of protecting the movable part from air currents, and from the disturbing influence of any electrified body, other than the fixed portion, differing from it in potential. In these instruments, the fixed portions consist of two sets of quadrant-shaped cells in metallic connection with each other, and formed by a number of parallel brass plates. These cells are fixed by an insulating support to the case of the instrument, and a terminal passes from them to an insulated binding screw on the outside of the case.

The movable portion in all the instruments is in metallic connection with the surrounding case. In the multicellular voltmeters this connection is made through the suspending wire. The movable portion carries the pointer, which indicates by direct readings the difference of potential between the two parts of the condenser.

The action of the instrument, shortly stated, is as follows:—When the fixed and movable plates are connected respectively to two points of an electric circuit, between which there exists a difference of potential, the movable plate tends to move so as to augment the electrostatic capacity of the instrument, and the magnitude of the force concerned in any case is proportional to the square of the difference of potential by which it is produced. In the multicellular voltmeters this force of attraction is balanced by the torsion of the suspending wire.

### The Kelvin Multicellular Electrostatic Voltmeter.

The arrangement of the parts of this instrument is shown in Figs. 239, 240, and 241. These figures apply to an early form of the



FIG. 239.

voltmeter, and differ in two matters of detail from the voltmeter as now made. For simplicity in manufacture the cells are now made with straight backs, and the plates looked at in plan are, therefore, triangular instead of square, as shown in Fig. 241. A coach-spring has now been interposed between the suspending wire and the spindle carrying the vanes, as explained below.

The insulated cells are formed of triangular brass plates fixed into saw cuts in a brass back piece so as to be equal distances apart and accurately parallel to each other. Two sets of those cells *C* are fixed relatively to each other, as shown in Fig. 240, by a vulcanite support to the sole-plate, so that their plates are

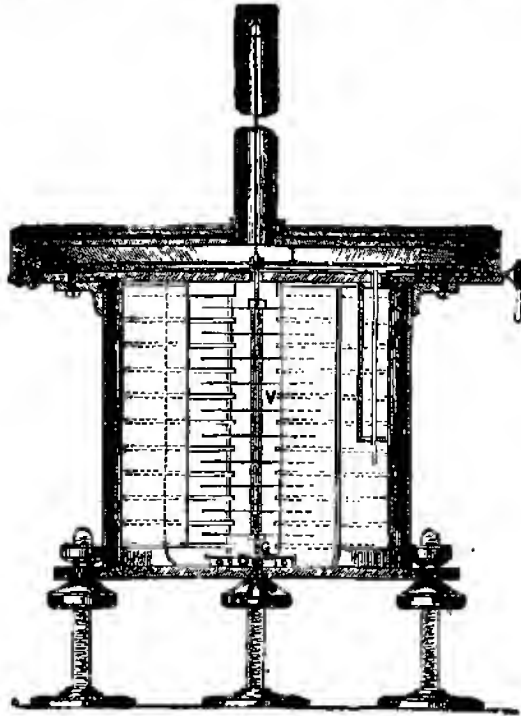


FIG. 240.

horizontal, and are completely enclosed within the brass cylindrical case of the instrument.

On the top of this cylinder is a shallow horizontal circular scale-box containing the scale of the instrument, and having a glass cover, which serves to protect from currents of air the movable indicator *I*, and the scale and interior parts from dust.

For the movable part a number of vanes, *V*, similar in form to those of the quadrant electrometer are used. These vanes are placed parallel to each other on a spindle with distant pieces between them. The top end of this spindle passes through a small hole in the sole-plate of the instrument, which forms the bottom of the scale-box, and is attached to a small coach-spring, which in turn is secured to one end of a fine iridio-platinum wire suspended from a torsion head at the top of a vertical brass tube.

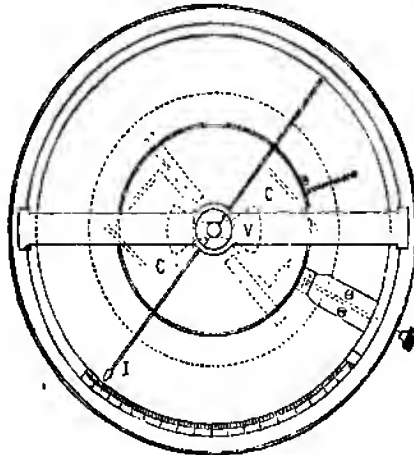


FIG. 211.

The torsion head may be turned by means of a forked key provided for the purpose, and is clamped, to protect it from accidental displacement, by a cap which screws on to the end of the tube. The coach-spring has sufficient resilience to allow the spindle to touch a guard stop, and so saves the suspension from injury in event of the instrument being roughly set down.

Two vertical brass repelling plates, which also act as guard plates to prevent the movable part from turning beyond its prescribed limits, are fixed to the bottom of the sole-plate. These



two plates carry a guide plate, *G*, with a circular opening in it, through which the lower end of the spindle passes. A little brass disc, or head, *D*, is attached to the end of the spindle, sufficiently large to prevent its passing back through the hole in the guide plate. Thus the movable part is effectually secured from swinging about so as to be injured, and by no possibility can it come into contact with the insulated quadrants. When the instrument is level the spindle hangs free by the suspending wire, so that, the

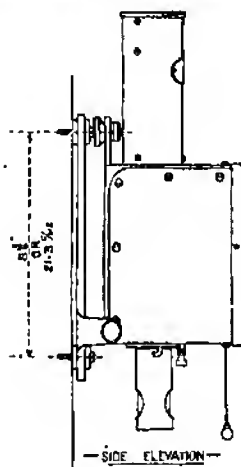


FIG. 242a.

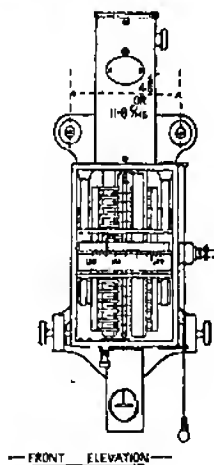


FIG. 242b.

vanes are horizontal, and each is in a plane exactly midway between those of two contiguous condenser plates.

An aluminium needle attached to the top of the spindle indicates, on the horizontal circular scale fixed to the upper side of the sole plate, the difference of potential between the movable and fixed portions of the condenser by direct readings in volts.

*Engine-room Pattern Multicellular.*—The description of the instrument given above refers to the horizontal scale or laboratory pattern. In the new engine-room pattern (Fig. 242 *c* and *d*), the

parts are in every way similar, but the instrument has a vertical scale. A vane attached to the spindle turns in an oil dash-pot and gives the instrument a dead-beat action.

*Portability.*—A small thumb-screw is placed in the centre of the base plate below the instrument, which can be screwed in so as to lift the weight of the spindle and vanes from the suspending wire and clamp the disc on the end of the spindle against the guide plate. A lifter or checker is also provided similar to that used in the magneto-static instruments.

A switch is attached to the insulated terminal of the instrument by which the voltmeter can be taken out of circuit when desired. The switch, after breaking circuit, puts the case and the insulated cells in metallic connection.

#### INSTRUCTIONS FOR THE USE OF THE MULTICELLULAR ELECTROSTATIC VOLTMETER.

When received from the maker the indicator needle with attached vanes will be found supported by means of the thumb-screw below the instrument, and also by the circular lifter, or checker, turned up so that the weight of the needle and vanes is taken off the suspending wire.

The scale is graduated to read directly in volts.

*To set the instrument up for use.*—(a) Unscrew the thumb-screw, and turn down the checker, so that the needle swings clear; (b) level the instrument so that the spindle of the vanes passes down centrally through the intersection of the two black cross-lines on the scale-plate.

*To adjust the zero, if necessary.*—Unscrew the cap on the top of the tube, remove the washer, turn the torsion head by means of the forked key until the pointer stands at 0 on the scale. Replace the washer and screw on the cap again. Before adjusting the zero turn the switch so that the insulated cells are in metallic connection with the case.

*Arrangement for portability.*—When the instrument is to be removed from place to place, see that the needle is lifted by turning up the checker, and when it is packed for use as a portable instrument, always screw up the thumb-screw as mentioned above.

As aluminium is electro-positive to brass, the instrument reads

about  $\frac{1}{2}$  of a volt too low when the positive pole of a battery or dynamo is attached to the upper or insulated terminal of the instrument; and about  $\frac{1}{2}$  volt too high if connected, in the opposite direction. With alternating currents it is correct.

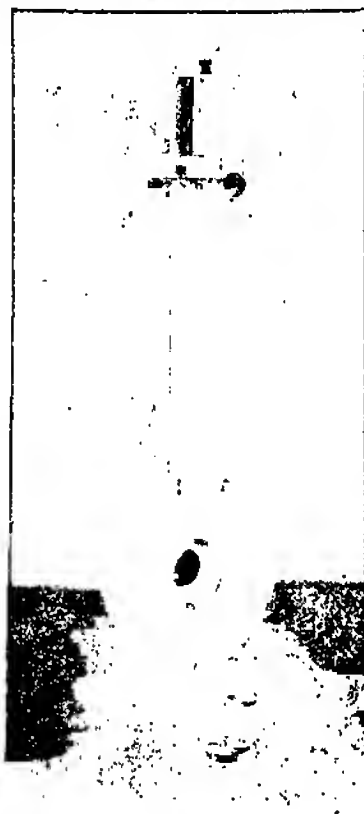


FIG. 243.

### Crompton D'Arsonval Galvanometer.

A convenient form of sensitive galvanometer, designed for laboratory use, with a large range of adjustment, and made by

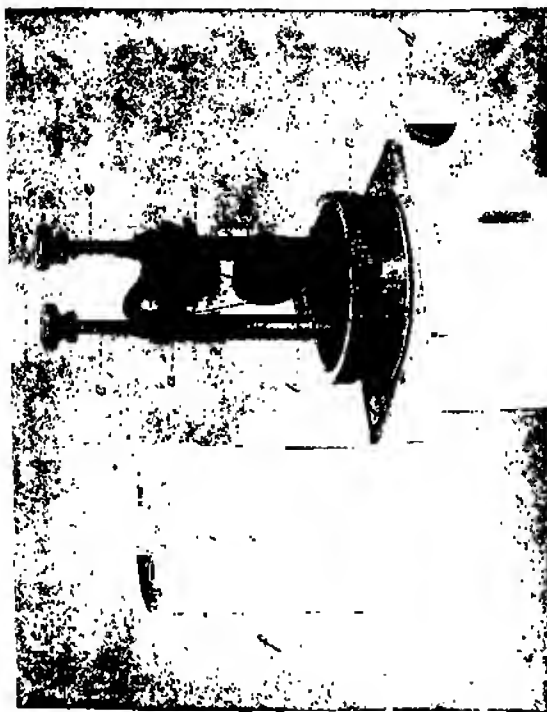


FIG. 244

Messrs. Crompton and Co., Chelmsford, is shown in Fig. 243, and the details of construction in Figs. 244 and 245.

The moving part of the instrument is shown in Fig. 245. A

circular coil of wire hangs by a bifilar suspension between the poles of a permanent magnet, an iron core being fixed in the centre. The suspension ligaments are of very thin copper strips, and are connected to the coil by means of a silver clip, which allows the coil to be easily disconnected.

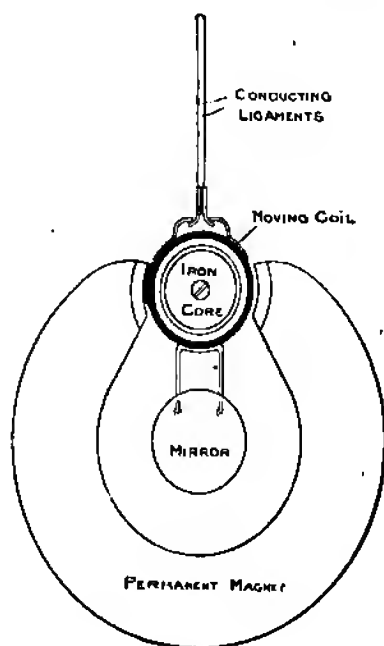


FIG. 245.

The mirror is hung from the coil by fine aluminium hooks passing through holes pierced in the mirror, so that this is easily detached, and is not distorted by the setting of cement or the pressure of a clip.

Fig. 245 shows the construction of the bifilar suspension head. The ligaments are attached to two pins *aa* fixed in a disc, by turning which the tensions of the two may be made equal. They pass over two pins *bb* placed on another disc, by turning which the distance between the ligaments may be adjusted, and the sensitiveness of the instrument increased or diminished.

The whole head is raised or lowered by turning the milled edge *C*, and is rotated slowly by turning the worm spindle *d*.

The two pillars by which the cover *f* is secured serve as the terminals of the instrument.

Coils are made having different numbers of turns from 100 upwards, and the sensitiveness of the instrument when adjusted to give a complete period of oscillation of from eight to ten seconds is nearly as follows—

TABLE XIII.

No. of Turns on Coil.	Resistance, including Ligaments.	Deflection of beam in minutes of Arc	
		For 1 Micro-volt.	For 1 Micro-ampere.
100	2 ohms	6	35
300	30 "	35	105
1000	1000 "	60	350

The coils can be fitted with small closed rings of copper, which damp their movements to any desired degree.

Without these the coils are for practical purposes perfectly ballistic.

An electric lamp used without a lens is the most convenient light for the above galvanometer, the filament being focussed on the screen by the mirror. This latter is large (25 m.m. diameter) and ground to a radius of one metre.

### Sensitive Portable Galvanometer.

When a Wheatstone Bridge has to be used for outside work, other than in a test-room or laboratory, or when fairly delicate tests have to be made on the "line," a portable type of galvanometer or detector which is as sensitive as possible must be

available. One of the best forms of such an instrument is illustrated in Fig. 246. It consists of a fairly flat-shaped coil of



FIG. 246.

aperture in the coil of wire.

The pointer protrudes outside one end of the coil and moves over a suitable scale, part of which is seen to the left of Fig. 246. A strip of mirror is let in under the scale and shows through an aperture in it, thus enabling errors due to parallax to be avoided. A needle clasper, actuated by a button on the edge of the case, enables the needle to be clamped during transport and damage to the pivoting thus avoided.

When no current flows the magnetic axes of coil and needle are perpendicular, when the pointer is at 0 at the middle of the scale. Then the effect of a current is to cause the needle to set itself parallel to the axis of the coil, so giving a deflection to one side or the other of zero. This form of instrument is a very sensitive one and very suitable for portable work with a Wheatstone Bridge.

### Parr's Direct-Reading Dynamometer Measuring Instruments.

These instruments depend for their action on the mutual force of repulsion between two circuits or coils carrying either the same or different currents, one circuit being fixed and the other movable. The instruments, which have been devised and perfected by the author, possess some very important properties

that it may be well to note here. They contain no iron whatever and very few metal parts, consequently they measure either the *true* watts, volts, or amperes, as the case may be, in any *alternating current* circuit, and are quite independent of the periodicity of the circuit. They are of the switchboard type, *direct-reading*, and have extremely open scales, extending over  $\frac{3}{4}$ th of the circular dial.

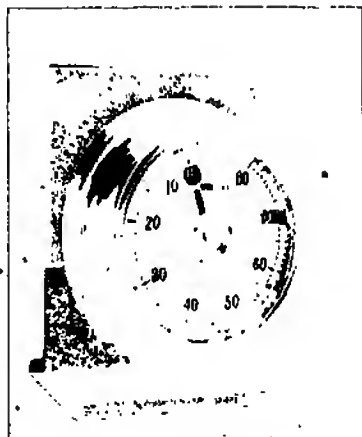


FIG. 247.

Fig. 247 shows an ammeter for 84 amperes, the scale graduations commencing at 3 amps. and continuing *nearly uniformly* to the end. Fig. 248 shows an internal view of this same 7-inch ammeter. As seen it consists of two fixed coils and two moving coils, carried at the end of a horizontal arm capable of rotating on a vertical spindle pivoted in jewelled centres. This spindle has rigidly attached to it a horizontal arm, to the end of which is fixed a flexible metallic strip that passes almost once round a special pulley carried by a horizontal spindle moving in jewelled centres and carrying the pointer at the front end, a



hair-spring, and balance-arm for the pointer. The moving coils and pointer are controlled by the hair-spring, the tension of which can be adjusted by a moving arm. Current is let into and out of the moving coils through non-spillable mercury cups. A damping vane and trough is added, also unspillable, by means of which the instruments are made *dead beat* to any desired



FIG. 248.

extent. The moving coils are clamped by a suitable arrangement during transport and seen to the right of Fig. 248. The moving coils are in contact with their respective fixed coils when the pointer is at 0 and no current flows. Repulsion ensues when a current is sent through the instrument, and according to whether it is an ammeter, voltmeter, or Wattmeter, so the pointer deflects and indicates directly the quantity to be measured. The instruments of course read equally accurately

on direct-current circuits, and having such very wide, open and uniform scales, a 6-inch instrument can be read with certainty many yards away.

### Siemens Torsional Voltmeter.

This instrument may be used either as an ammeter for very small currents or as a voltmeter with a very extended range.



FIG. 242.

and provides a good example of the method of converting one into the other.

It consists of two coils, wound with fine insulated wire, and of elongated oval section, with their axes collinear and horizontal. They are connected in series and wound so that the north pole

of one faces the south pole of the other, i.e. the two coils may be regarded as one coil with a gap in the centre.

Between the coils is placed a horse-shoe or bell magnet suspended by a silk fibre. A spiral spring is attached to the magnet and to a torsion head at the top of the case, so that by turning the head, a twist is applied to the magnet, proportional, of course, to the angle of turning of the torsion head. To the magnet is attached a pointer, for the zero position of which the magnetic axes of coils and magnet are at right angles.

The magnet also carries an aluminium vane, moving between two brass checks which act as stops, the vane assisting in stopping the vibrations.

On passing a current through the coils so as to induce the polarity indicated by the small letters *ns*, *ns* (Fig. 250), which represents a symbolical sectional plan of the coils *C* and needle *NS* in a horizontal plane passing through their centres, the magnet *NS* tends to turn *counter-clockwise* in the direction of the arrow, so that its magnetic axis would coincide with that of *ns*, *ns*. Then the angle through which the torsion head has to be turned (in a *clockwise* direction) in order to bring the magnet pointer back to zero measures the moment of the couple exerted by the coils on the magnet, i.e. the current flowing through those coils.

The coils *C* together have a resistance of 100 ohms in the instrument illustrated, and it is wound with such a number of turns that when 1·7 volts are placed across the terminals of the instrument itself, the torsion head makes one complete turn or 170 divisions to bring the magnet pointer back to zero. Hence 1 scale division = 0·01 volt. To make it read 0·1 and 1 volt per division, 900 and 9900 ohms respectively must be put in series with the instrument, when the extremities of the combination will now form the voltmeter terminals. These extra anti-inductive resistances are contained in the receptacle to the

left in Fig. 249, which is provided with a plug top for inserting these resistances at pleasure. They should be wound with a

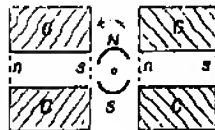


FIG. 250.

material having a high specific resistance and low temperature coefficient of variation of resistance for reasons already given.

This instrument can be used as a low-reading ammeter, for since 1 division = 0.01 volt and the whole resistance of its coils = 100 ohms,  $\therefore$  1 division =  $\frac{0.01}{100} = 0.0001$  ampere.

**Adjustment of voltmeter.**—If the magnet has been clamped for transport, release it by turning the milled-headed rod which passes through the edge of the base at the back.

Very carefully level the instrument by turning the levelling screws so that the pointed pin, attached to the moving magnet, is just over the cross marked on the fixed stud under it. The moving system should now be quite free, at all events laterally. See therefore that this is the case.

The height of the moving magnet can be adjusted to give freedom of motion by carefully turning the milled-headed pin which passes into the torsion head at the top of the instrument. Set the torsion head with its pointer to zero, and then bring the magnet pointer to its zero by turning the wooden base which carries the coils. Fix the instrument in this position by turning the milled-headed pin which projects from under the base. In using the instrument thus adjusted to measure current, place it directly across the low resistance provided, and to measure higher voltages connect it in series with the separate anti-inductive resistance provided with it, when the extremities of the combination will then be the terminals of the voltmeter.

**Caution.**—Make quite sure that the correct resistance is plugged in, otherwise the instrument may be fused up. The plug may be used as a make and break key. Being a + and - instrument, it must be connected up in circuit that the magnet pointer tends to move in the opposite direction to that of the torsion head.

### Siemens Electro-Dynamometer.

This instrument depends on the electro-dynamical action of one circuit which carries a current on another circuit carrying either the same or a different current, and is illustrated in Fig. 251. It consists of a base supported on three levelling screws and carrying

an upright standard, to which latter is fixed two distinct stationary coils usually wound with two different gauges of wire and number of turns so as to obtain a wider range of sensitiveness and measurement than would be possible with only one fixed coil. A movable coil, the plane of which is perpendicular to that of the fixed coils in the normal position of the former when actually



FIG. 251.

measuring a current, is suspended by means of a silk fibre from a torsion head, at the top of the instrument, carried at the centre of a graduated scale, which is itself screwed to the top of the standard.

A rather long helical spring, composed of a sufficient number of turns, has one end fixed to the under side of the torsion head and

the other to the top of the moving coil, which is thus controlled by the turning of the head. Electrical connection is made with the moving coil through two mercury cups into which its ends dip and which are directly in a line, *under* the point of suspension. A milled-headed pin or rod, carried by a light support, seen at the back of the scale, passes through the hollow torsion head, and has attached to it the silk thread that suspends the movable coil and which passes down through the torsion head. Hence, by turning the rod round the moving coil can be raised or lowered so as to clear the other fixed fittings. The moving coil, which may consist of more than one turn, can be raised and clamped during transport by a spring clamp (not seen in Fig. 251) at the back, controlled by a milled nut. The instrument requires to be carefully levelled before using to ensure perfect freedom with the moving coil. The levelling screws and spirit-level are added for this purpose, though sometimes a plumb line is used in place of the latter. The fixed and moving coils are in simple series; one end of each of the fixed coils goes to the outside terminals, the other ends both to the top mercury cup and the lower cup to the centre or common terminal. Thus there are two sensibilities, viz. the moving coil in series with either fixed one, according to whether the centre and left or centre and right pair of terminals are in use. Since at the actual moment of measuring a current by the dynamometer, the fixed and movable coils are always in the same position (*i. e.* their axes perpendicular) relatively to one another, due to the index pointer on the moving coil always being brought back to zero by turning the torsion head, the couple or force, whether of attraction or repulsion, exerted by one coil on the other is  $F \propto C_1 \times C_2 \propto C_1 \times C_1 \propto C_1^2$  where  $C_1$  and  $C_2$  are the currents in the two coils which are equal or the same. But this force is just balanced by the force of torsion exerted by the spring  $\propto$  angle of torsion or the deflection  $D$  of the torsion head. Hence,  $D \propto C^2$ ,

$$\therefore C \propto \sqrt{D},$$

$$\text{or } C = K\sqrt{D} \text{ amperes,}$$

where  $K$  is the constant for the particular fixed coil used which gives an equation of equality.

This is the law of the *Siemens electro-dynamometer*.

Some of these instruments have scales divided into numbers  $\propto$  to the square roots of the usual divisions, and in such cases the

current  $C = K \times$  scale reading simply. In using these instruments care must be taken to either twist the "leading in and out" leads together, or run them very close so that the swing coil may not be affected by the current in these leads.

In calibrating or using the instrument with direct currents, it must be so placed that the plane of the suspended coil when in its zero position is perpendicular to the plane of the magnetic meridian of the earth. The reason for this is, that when the swing coil carries a direct current it is acted on by the earth's magnetism independently of the action due to the current in the fixed coil, and the position of rest for the first cause is when the planes of the magnetic meridian and swing coil are at right angles. For alternating currents there is no such action.

### Siemens Dynamometer-Wattmeter.

Except for the swing or movable coil, this instrument is precisely similar to the preceding dynamometer. It is illustrated in Fig. 252, which indicates two or three alterations to the general form of the Wattmeter, which the author has thought it beneficial to make. The one illustrated is provided with two thick fixed coils, as in the dynamometer, Fig. 251, connected directly to the three large terminals in the middle, so that two distinct sensibilities can be obtained instead of usually only one.

The swing coil now consists of many turns of fine insulated wire wound on a light rectangular frame of ebonite or boxwood. Only a few of the turns are wound inductively, the rest being doubly wound and therefore non-inductive. The total resistance of the swing coil is, however, that due to the sum of all the turns, which may amount to 5000 ohms or more. Current is led into and out of the swing coil through thicker wires soldered to the fine wire and which dip into the two mercury cups. These last-named are directly connected to a separate pair of small terminals seen on the extreme right and left, having no electrical connection whatever with the thick coils.

The scale is provided with a mirror for the purpose of avoiding errors due to parallax in reading the position of the torsion head pointer. The mirror glass covers the scale, but a circular strip of

silvering is removed just over the scale, enabling it to be seen but preventing it getting dusty and dirty. In all other respects this Wattmeter is the same as the dynamometer shown in Fig. 251. When the swing coil is returned to its zero, by turning the torsion head, we have as before its deflection  $D \propto C_1 \times C_2$  but if  $C_1 =$  the



FIG. 252

main current and  $C_2$  the current in the fine coil, which is placed across the mains, and therefore is  $\propto$  to the voltage ( $V$ ), we have  $D \propto C_1 V \propto$  Watts,

or Watts ( $W$ )  $= KD$ ,

where  $K$  is the constant of the instrument for the thick coil used. Thus by combining the voltmeter and ammeter in one and the



same instrument, the deflection of the new instrument so formed measures the power in Watts absorbed by any circuit. Though the Wattmeter is of no great use in direct current work, since we usually require both the amperes and volts separately and can always multiply them and so obtain the power when desired, the instrument is of incalculable value in alternate current work, since, if nearly non-inductive, it is the best known means of obtaining the *true power* in such a circuit, the product= $\text{amps.} \times \text{volts}$  not giving this quantity.

The same precautions are necessary in using the Wattmeter as in the dynamometer, and in addition errors may arise through the warming up of the swing coil and consequent alteration of its resistance, as in the case of electro-magnetic voltmeters. The error that may be introduced by the earth's field is explained on p. 580.

### Change-over Switch.

Fig. 253 represents a form of switch suitable for large currents and which can be used in one or other of four ways as follows—

(1) As a single-way, single-pole switch by connecting to the centre and either of the end terminals on the same side.

(2) As a single-way, double-pole switch by connecting the centre and an end terminal on the same side in one main, while the other centre and corresponding terminal at the same end is put in the other main.

(3) As a two-way double-pole switch by connecting the common circuit to the two centres and each branch circuit to the pair of terminals at one end.

(4) As a reversing switch by connecting the circuit or portion to be reversed to the centre pair and the main current to the pair at either end, cross connecting the corner terminals at the ends by temporary wires.

The figure shows the construction fairly clearly, and it consists of two metal blades carried by smaller extensions at their lower extremities and capable of turning about a horizontal axis in the upright standards which form part of the base carrying the middle terminals and inner wedge blocks. Four similar wedge blocks

(two at each end) are carried by metal bases on which the four end terminals are fixed. When the blade levers are up (as seen), the metal parts, electrically connected to the six terminals, are insulated from each other, as the lever blades are also insulated from each other, their upper extremities being fixed by an insulator cross-piece to which the handle is fixed. When the blades are



FIG. 253.

pushed down one side or the other into their respective pairs of wedge contact blocks they short circuit these, thus joining the centre and end terminals on one side together, and likewise those on the other side.

### Keys.

A form of key, which, though not very portable, is extremely useful in a test room, is shown in Fig. 254, and is otherwise known as a Pohl's commutator. It consists of a wooden, though preferably polished ebonite, base *M*, containing 6 small pure-copper

the circuit to be reversed to the other pair  $T_2$  and  $T_4$  or vice versa.

(4) As a 2-way key by joining one main to any one terminal, e. g.  $T_1$  and the branches to  $T_2$  and  $T_4$ .

### A Highly-Insulated 2-Way Spring Tapping Key

is shown in Fig. 256, and consists of a well-polished ebonite base  $B$ , supporting at one end a well-polished ebonite standard  $S$ , to which is fixed two brass contact terminal blocks  $t_1$   $t_2$ .

Let into and carried by the top of the standard  $S$  is an ebonite rod  $R$ , which at its other end supports an ebonite

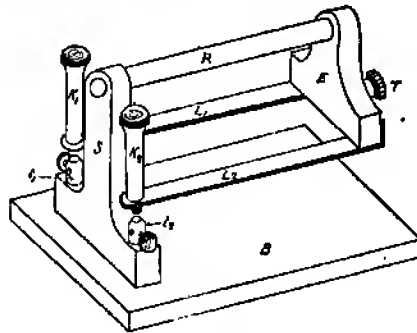


FIG. 256.

block  $E$ . To  $R$  is fixed two springy brass strip levers  $L_1$   $L_2$ , electrically connected together and to the common terminal  $T$  at that end.

The free ends of the spring strips are provided with rather long ebonite knobs  $K_1$   $K_2$  for the finger of the operator to tap.

In the use of this key, if the high-potential wire is connected to the common terminal  $T_1$  the path of any leakage lies from  $T$  across  $E$ , then along  $R$  and down  $S$  to the base  $B$ , and thence to earth. This being long gives the key a high-insulation resistance,

and to still further increase this, all the ebonite parts should be well polished and quite clean and free from dust.

It will be noticed, that since there is a lever to each way, it would be possible to press both at once. Unless otherwise directed this must be absolutely avoided, as serious damage may be done in consequence.

Fig. 257 shows, in plan, a convenient form of 2-way *sliding* switch. It consists of a wooden or ebonite base  $B$ , to which is fixed three terminals  $T_1$ ,  $T_2$  and  $T_3$ . The two latter,  $T_1$  and  $T_2$ , make permanent contact with the *contact blocks*  $b_1$ ,  $b_2$  respectively, while  $T_3$  acts also as a centre for the contact lever  $L$  to turn on. The knob  $K$  is merely for the purpose of conveniently turning the lever  $L$ .

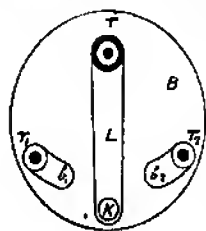


FIG. 257.

In the position shown in the figure, there is no connection between  $T_3$  and either  $T_1$  or  $T_2$ , but by turning  $L$  so as to rest on  $b_1$  or  $b_2$ , then connection is made between  $T_3$  and  $T_1$  or between  $T_3$  and  $T_2$  respectively.

It will be noticed that only one contact can be made at one and the same time. This is an advantage in some cases, where the simultaneous making of both ways might cause an accident.

### Arc Lamp Photometer Cradle.

In the photometrical testing of electric arc lamps it is necessary to be able to have the means of measuring the candle-power of the arc in several directions, making various angles with the horizontal line passing through it. In some cases this is done by raising or lowering the lamp vertically, the beam from it being reflected along the bench by a fixed plane mirror suitably placed, but capable of rotating on an axis.

The author has devised the cradle shown in Fig. 258, in which the lamp to be tested is placed. The lower part is a rigid frame.



FIG. 258.

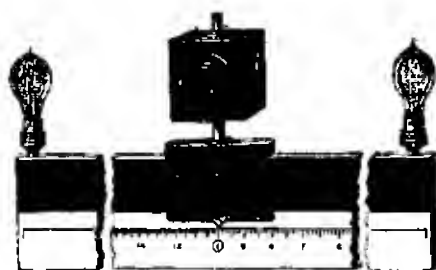


FIG. 259.

work which is placed on the photometer bench and carries an upper frame capable of moving round a hollow tubular horizontal axis, which latter is itself capable of moving in the fixed frame and has attached to it a pointer, seen in Fig. 258, just above the two large terminals. In this upper frame is placed the arc lamp, which can therefore be inclined at any angle to the vertical, as read off by the pointer on its scale.

The carbons of the lamp are first adjusted so as to touch at a point in the axis of rotation, as seen through the tubular axis. Thus the arc in turning as the cradle is turned, always maintains the same position relatively to the photometer bench, and the author has found that next to no difficulty in the regulation of the arc by its auto-mechanism occurs up to 50° or 60° from the vertical. After this the carbons have to be partly regulated by hand.

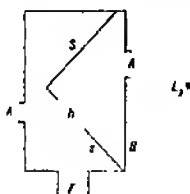


FIG. 260.

### Direct-Reading Bar Photometer.

This form, due to Mr. Trotter, has a direct-reading scale on its bank which shows without calculation the ratio between the standard and lamp under test when the sight-box seen in the middle of the bank (Fig. 259) is moved so as to obtain an equal illumination of the screens. The general arrangement is very suitable for making rapid tests on electric glow lamps, as slight variations of E.M.F. affect both lamps equally and do not cause appreciable errors. Fig. 260 shows a sectional plan of the sight-box BB, in which AA are the apertures at the sides to admit the beams of light from the two lamps  $L_1, L_2$  to be compared. SS are two screens, the illuminations of which are compared. One of these contains a star-shaped hole for the purpose of enabling the further screen to be seen through the funnel or window F, through which the observer looks.

### Illumination Photometer.

This is a portable direct-reading instrument devised by Mr. A. T. Trotter, by which the illumination at any spot in a street or building can be at once measured in terms of the illumination given by an amyl-acetate standard of light, this being found more reliable and less troublesome than ordinary standards of light. A general view of the instrument is shown in Fig. 261, and a sectional elevation in Fig. 262.



FIG. 261.

#### INSTRUCTIONS FOR USE.

Remove the end cap with the mirror *M* on it by the bayonet joint; remove the cover from the lamp and light it, then replace the end cap. The flame can now be seen in the mirror. The top of the flame should just touch the point of the bent arm.

The flame is raised or lowered by screwing the lampholder in or out by its lower end. By unscrewing the holder completely it can be drawn out for refilling.

Having adjusted the flame to the right height the cap on the top is removed and the photometer is set so that the paper screen *S* is horizontal.

The general illumination to be measured falls on this screen *S*. Across the centre of it is a small slit *T* through which an inside screen *R* illuminated by the standard lamp can be seen. The observer's eye must be vertically over the hole in the screen. The inside screen *R* is then adjusted by the outside arm *P*. When the illumination of the outside screen *S* is greater than that of the inside, the slit *T* will appear dark; when less the slit will appear bright. With a little practice the slit can be made to nearly, if not quite, vanish; the illumination is then shown on the scale *F* by the pointer *P*. The unit used is the illumination due to one standard candle at one foot; that is, if a balance is obtained when the pointer is at "1," the illumination is equal

to that of 1 standard candle at 1 ft. distance, if at "2" the illumination is twice this, and if at ".1," one-tenth of that which would be given by a standard candle a foot away.

The inside screen *R* has a slight blue tint which to a great extent removes the colour difficulty.

A slightly yellow upper screen is provided for measuring with very blue lights.

Be careful the eye is vertically over the slit. Holding one

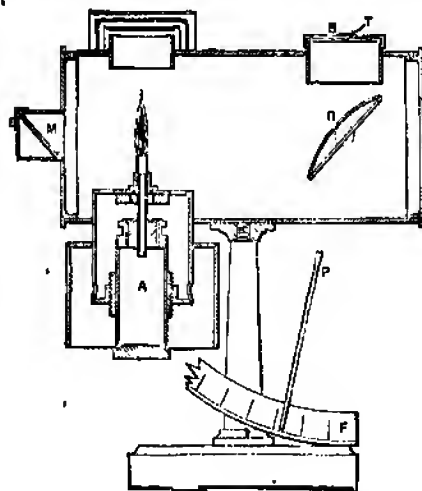


FIG. 262.

finger near the eye and between it and the hole will make it easier to get the vertical line.

Be careful to stand so that the body is not between the screen and any source of light.

The slit must be square across the instrument.

See that the height of the flame is right before and after each reading; the flame sometimes increases a little, especially just after being lighted.



The flame is not affected by a gentle breeze, and on windy nights the instrument can easily be shielded by a piece of cardboard or brown paper.

Only pure amyl-acetate must be used, and the wick must be cut square across without ragged points.

Keep the cap on over the screen when not in use, and do not let the screen get dirty.

There is a small pin at the centre of the pivot of the arm; when the instrument stands so that its shadow thrown by any lamp falls on the scale, it gives the cosine of the angle of incidence, having which the actual C.P. can be calculated. The height of the lamp is equal to the distance from the post when the shadow falls at  $45^\circ$ .

### Photometer Screens.

Of these there are many different types, all of course effecting the same purpose, namely, that of enabling equality of illumination due to two different sources of light to be visibly determined and hence their relative intensities. Fig. 263 shows a form of Bunsen screen arranged inside a "sight-box" seen with its top or lid open to enable the inside to be seen. It consists of two discs of plain paper having its centre portion greased in the form of a star. These discs are seen one near each end of the "sight box," which is dull black inside and prevents stray light due to external or internal reflection from getting to the Bunsen standard discs or screens. Two vertical plane mirrors are placed as shown symmetrically with regard to the discs, and each at  $45^\circ$  to the back of the box.

The images of the two discs can be seen in the two mirrors through two rectangular open windows in the box shown in front of Fig. 263, and thus the intensities of their illuminations can be compared by the eye. It should be noticed that the sight-box illustrated in Fig. 263 cannot give true results, since the ratio of the squares of the distances from the light sources to the standard discs and again to the centre of the box are not the same. The box is given, however, to indicate this fact and to act as a warning to users of it. Another form of this screen is shown

resting on the top of the "sight-box," illustrated in Fig. 264. Here there is but one disc with a plane mirror on either side of it, making equal angles with it, and enabling an image of each side of the screen to be seen without looking directly at the disc itself.

The lower part of Fig. 264 illustrates a form of balancing screen due to Jolly, and consisting of two rectangular blocks of clear paraffin wax, cemented together but separated by a film of silver paper so as to prevent direct transmission of light right

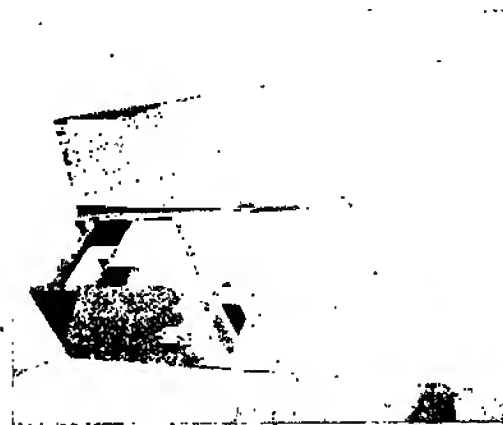


FIG. 263.

through the two blocks. They are placed inside a sight-box to prevent stray light getting to them, hence the two blocks will appear equally bright when the two sources of light to be compared, placed on either side of the sight-box, illuminate them equally.

One of the best photometer screens is that due to Messrs. Lummer and Brodhun, and is shown symbolically in Fig. 265. In this type the light from the two sources to be compared falls on a screen *SS*, having equally light surfaces. The rays are then

Q Q

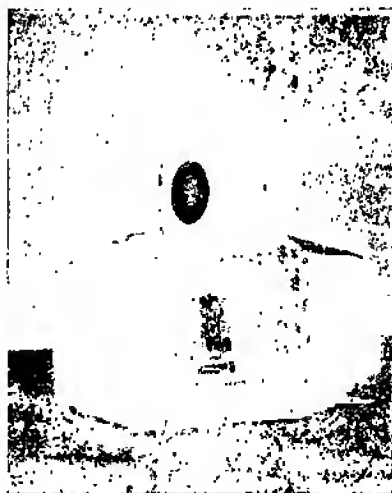


FIG. 264.

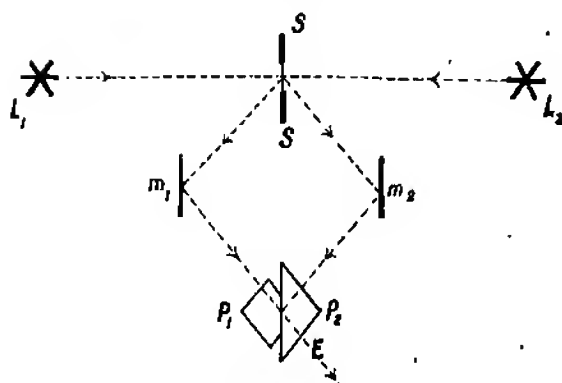


FIG. 265.

reflected by two similar plane mirrors  $m_1$  and  $m_2$  to two prisms  $P_1$  and  $P_2$ , of which  $P_2$  is the ordinary form, while  $P_1$  has a curved surface one side which touches  $P_2$ .

The reflected rays from  $m_1$  are able to pass through the combination to the eye placed at  $E$ , while those from  $m_2$  are deviated to  $E$  also. Thus the screen  $SS$  when equally illuminated both sides cannot be seen at  $E$ .

### "Methven Screen" Photometric Standard of Light.

When used with just an ordinary amount of care this standard of light is one of the most convenient and accurate, requiring no elaborate preparation, as in the case of some other standards, before being used. A standard two-slot "Methven screen," together with a carburetter, is shown in Fig. 266. The former consists of a vertical brass plate or screen, bent round at right angles at the bottom, and to the under side of which is fixed a tubular metal foot which fits into the hollow standard supporting the whole screen.

To the upper side of this angle-piece is fixed a London Argand burner provided with a stellite cone and a cylindrical glass funnel. Two pairs of brass bars are screwed into the screen at respectively  $2\frac{1}{2}$ " and 3" above the top of the burner. The screen has a hole at its centre across which slides a silver plate containing two rectangular windows, the size of which are determined by the height of the flame and the C.P. of the light emitted from them. This in the Methven screen, shown in Fig. 266, is 2 C.P. either when the mean height of the peaks of the flame are on a level with the two top bars and the long narrow slot in use with ordinary coal-gas, or with the flame on a level with the two lower bars, the short broad slot and the coal-gas carburetted. The carburetter is shown on the left of Fig. 266, and is merely a metal reservoir containing pentane liquid, which is highly volatile, the vapour mixing freely with the coal-gas and enriching it as this latter is made to pass through the receptacle by manipulating the three stop taps seen

on the branch tubes. For a more detailed description of the Methven screen, see Slings and Brooker's *Electrical Engineering*.



FIG. 266.

It should be noticed that the position of the screen is rather misleading, arising from the fact that it is shown turned round out of its normal position to show more clearly the burner, etc.

### Adjustable Carbon Rheostat.

An extremely useful form of continuously adjustable rheostat, suitable for large currents as well as small ones, is illustrated in Fig. 267, this particular one being capable of carrying about 25 amperes continuously or 30 to 40 amperes for short periods of some minutes' duration.

It consists of a row of square flat plates of hard gas-retort carbon, resting on a fairly broad ledge of slate or some other suitable insulating material screwed to an iron bar underneath

it which is fixed to the ends of the framework of the rheostat. These ends are also fixed to tie rods at the sides, to the top of each of which is screwed an over-lapping strip of vulcanized fibre to guide the plates, and at the same time not to short-circuit them. The row of carbon plates are terminated by thick cast-iron plates, extended at the top and carrying the terminals shown. The left-hand terminal plate is insulated from that end by a plate of vulcanized fibre, while the row of plates is com-

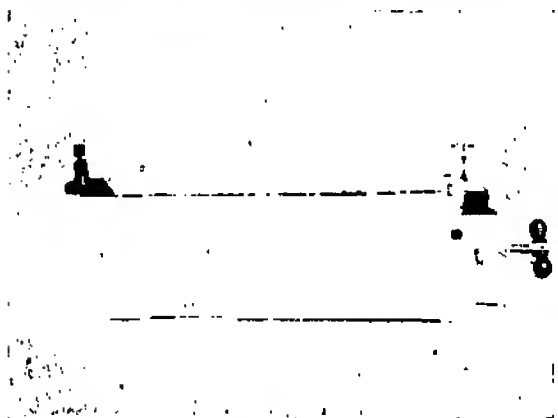


FIG. 267.

pressed against this by a screw working against the right-hand end. In case at any time the right-hand terminal plate is removed and inserted in some intermediate position in the row, an extra cast-iron plate the same size as the carbons is provided this end to guard against the friction of the carbons should the screw press on them by mistake. One valuable advantage of this rheostat is that, being non-inductive, it can be used with alternating currents in cases where many other forms of rheostats could not be. The resistance varies from a minimum when the plates are tightly compressed, to a maximum when they are loose.

### Incandescent Lamp-Box Resistance.

In many tests on alternating current appliances, such as transformers, alternators, etc., difficulties arise in obtaining a non-inductive resistance in which to take up the output of the appliance, for, as is well known, the product of the volts and amperes only represents the *actual* or *true* power in Watts absorbed, *providing* the load-absorbing *rheostats* are truly *non-inductive*.

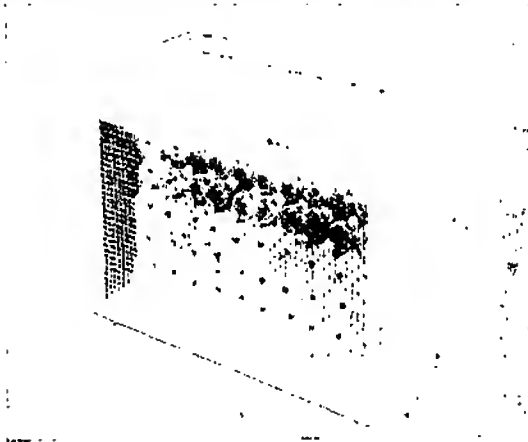


FIG. 268.

This can be obtained with specially wound rheostats made of ordinary iron wire or other special alloy. A water rheostat is, however, simpler, though not perhaps so convenient to manipulate, while Fig. 268 illustrates a still more convenient form of non-inductive (to all practical purposes) rheostat, which the author has designed for his own purposes, and one that is fairly portable with care. The particular one shown consists of a containing case and box, with an internal partition which supports some 60

or 70 glow lamps, composed of 8, 16 and 32 C.P. lamps, capable of absorbing some 7 or 8 E.H.P. All the woodwork the lamp side of the partition is covered with a double layer of asbestos cloth, and the front of the box is protected only by a grating to allow of free circulation of cold and hot air. Each lamp is connected to its own pair of mercury cups in a special switch-board, seen on the top of the box towards the back, by means of which the lamps can at once be connected *all in parallel, all in series*, or



FIG. 269.

in any other intermediate combination, to suit requirements. The side opposite the grating hinges down, giving free access to the lamp-holders and connections to the mercury switch-board. This lamp-box resistance requires care in carrying about, as the mercury tends to come out of the two long slots if the box is much tilted. It is, however, extremely convenient, and when the lamps are used in parallel in alternating current work, their effective self-induction is extremely small, so that when absorbing the load from the secondary side of a transformer (say), the  $\text{amps.} \times \text{volts}$  will be the true power absorbed, i. e. developed by the transformer.



### Adjustable Rheostat.

Fig. 269 shows a convenient wire-wound rheostat, capable of step-by-step variations between 0 and the maximum resistance, which is about 40 ohms, and of carrying continuously 6 or 7 amperes. It is a form of rheostat eminently suitable for regulating the shunt circuit of either a dynamo or motor of that type. As will be seen with reference to the figure, it consists of a box or case containing the coils (not seen), and which is fitted with a top carrying the multiple way lever switch of the form shown. The circular row of studs seen in the upper part of Fig. 269 are connected to the coils inside in such a way that the right-hand end block gives the full resistance of all the coils in series between the terminals at the top, when the lever is on this block. The rheostat, being intended to be used in a vertical position, has a wire grating at the top and bottom in order to obtain a cooling circulation of cold air through the interior. The coils inside are strung between insulators, so that even if they do get very hot, the inside of the box will not be much harmed.

### Continuously Variable Rheostat.

This rheostat is of the same type and make as that illustrated and described relative to Fig. 271, consequently a further description is unnecessary. By winding the rheostat with, say, the same gauge in a higher specific resistance material than platinoid, such as manganin, or roostene, it is easy to obtain a resistance which can be varied perfectly continuously from something like 30 or 40 ohms down to 0, and that will carry a maximum current of about 4 or 5 amperes. This in a test-room or laboratory is extremely useful, enabling very fine adjustments of resistance, and consequently of current or pressure, to be obtained when desired.

The reader is referred to the description of the same make of rheostat shown in Fig. 271.

### Improved Rheostat.

The object of the rheostat, invented over forty years ago by Wheatstone, is to provide an electric resistance which can be varied continuously.

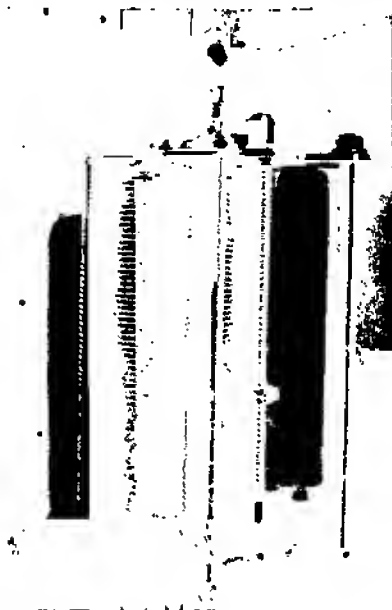


FIG. 270.

The instrument shown in Fig. 271 is an improved form (due to Lord Kelvin) of Wheatstone's rheostat, in which the wire is guided from one cylinder to the other by a fork carried along through the requisite range by a nut travelling on a long screw.

shaft. This screw-shaft carries a toothed wheel which turns the two cylinders by means of toothed wheels attached to their shafts. A watch-spring, as in Jolin's improvement of Wheatstone's rheostat, keeps the wire always tightened to the proper degree. A leather buffer at each end of the range of the nut acts as a guard against overwinding in either direction.

In a high resistance rheostat the conducting cylinder and the wire are both of platinoid, a metallic alloy having properties which make it specially suitable for the purpose. It has very high electric resistance, very small temperature variation of resistance,

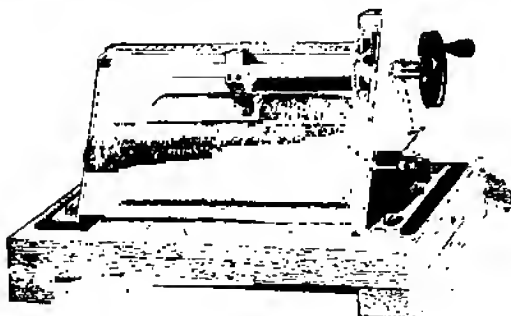


FIG. 371.

and its surface remains almost or altogether untarnished in the air. On account of the last-named property the contact between the wire and the conducting cylinder, and continuity in action, which was a great difficulty in the old form of apparatus, is very complete.

In a low resistance rheostat the conducting cylinder in this instrument is made of brass, nickel-plated so as to avoid tarnishing, and the wire used is copper, also nickel-plated. The rheostat can be supplied to carry currents as high as 30 amperes. The relation between material resistance and current for these rheostats is as follows, viz.—

TABLE XIV.

Wire.	Approximate Resistance.	Maximum Current.
Platinoid.	600 ohms.	0.25 amperes.
"	100 "	2.0 "
"	20 "	10.0 "
Copper.	0.4 "	30.0 "

## Continuously Variable Rheostat.

Fig. 272 illustrates another slightly different form of Kelvin's improvement on the original Wheatstone's rheostat. The actual

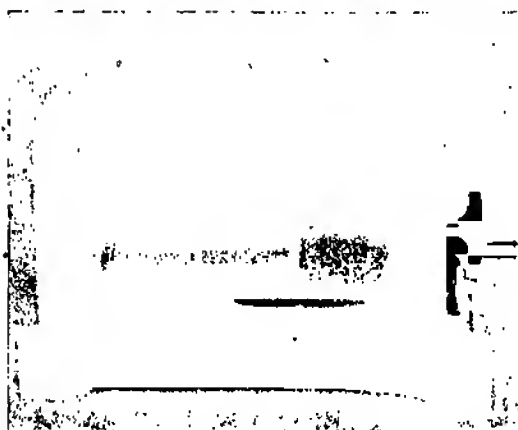


FIG. 272.

construction is the same as that described in the two preceding, Figs. 270 and 271, except that the one here shown is intended for finer and lighter work, as seen from the smallness of the parts and gauge of wire employed. The second cylinder is just behind the one shown in the figure. Fairly fine wire is used, and

the rheostat so wound may have a resistance of about 100 ohms as a maximum, capable of carrying one or two amperes. Like the "Wirt" form of resistance, described in *Practical Electrical Testing* by the author, it forms a most useful type of resistance for small work, such as calibrating low resistance voltmeters, enabling a series of different readings to be taken without actually altering the number of cells in the E.M.F. used.

The reader should refer to the description of the principle of this form of rheostat which is given relative to Fig. 271.

### Fixed Standard Low Resistances.

There are many different forms of these depending to a great extent on the value of the resistance, and also on the particular make. Fig. 273 shows a set of five different forms of standard low resistances made by Messrs. Crompton and Co., and primarily intended for use with the potentiometers made by them also. The resistances can, of course, be used for any other purpose than this which requires a standard resistance of accurately known value, capable of carrying large currents without sensible heating or alteration.

The one shown standing on end at the top is of a slightly different form to the rest, being of the tubular water-cooled type.

These resistances consist of a sheet or strip of metal, or a coil of wire, each provided with four terminals, two for connection to the circuit and two for connection to the potential leads.

The smaller resistances take the form of a coil or spiral fixed in a mahogany frame, and also of flat strips either bent or straight, the largest size—300 amperes and over are of sheet or water-cooled type.

They are constructed of manganin, an alloy which has been thoroughly tested, and which has the great advantage that within ordinary limits of accuracy (say one part in 1000) no temperature correction whatever is necessary: but for measurements with the potentiometer requiring an accuracy exceeding this, a curve, giving the temperature value for the whole range of

current that the instrument is capable of carrying, is supplied with each resistance.

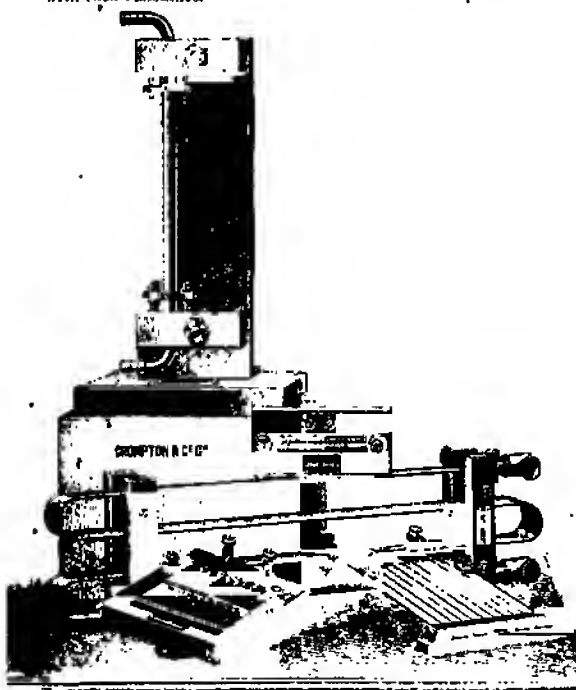


FIG. 273.

Such a curve, together with other forms of adjustable and fixed standards of low resistance, are given in the author's work entitled *Practical Electrical Testing*.

### Stand Coil Rheostat.

A most convenient form of current rheostat of a portable nature, at all events one that can be moved comfortably about any testing-room, is illustrated in Fig. 274. It consists of an

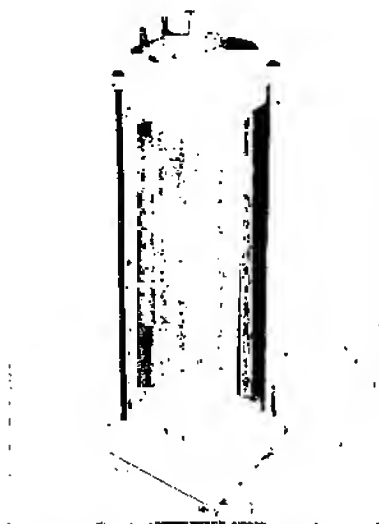


FIG. 274.

iron frame or stand, of as light a construction as possible, in order to be light, between the top and bottom of which are stretched bare wire spirals of either iron or some high-resistance alloy. These coils are spaced sufficiently far apart to prevent them easily touching should the rheostat receive a slight knock, and are all connected in series, their junctions being connected

to a multiple way switch seen on the top. This latter consists of several studs or blocks arranged in a circular form and having their upper surfaces turned up in the middle so as to be quite level. A suitable spring lever pivoted in the centre of the ring of blocks is capable of turning almost once round between two stops and of making contact with each block as it passes over it.

One of the two-terminals of this stand coil rheostat (seen on the top) is connected to the lever centre, and the other to one end of the series of coils. Thus the resistance between the terminals can be varied from nothing (*i. e.* short circuit) to the maximum by as many steps as there are contact blocks on the switch. A great mistake, which is usually made by rheostat makers, is to use the same gauge of wire throughout the rheostat, for clearly the gauge should increase as we begin to cut out, since the current is thereby increased also. The above rheostat, made to the author's designs, contains about four or five gauges of wire.

### Three-Phase Liquid Rheostat.

For three-phase alternating current work there are two distinctive forms of rheostats needed, differing merely in the terminal arrangements. One form may be termed a "*through*" rheostat, which would be required for regulating the current supplied by a generator to, say, a motor; the other form may be termed a "*closed*" rheostat, which would be required for absorbing the load from a generator.

In all forms the rheostat must operate equally on each of the leads of a three-phase system, otherwise the balance and symmetry of the currents will be thrown out and will cause considerable trouble. Three-phase rheostats may be either metallic or liquid in nature, but in any case the moving contacts must move simultaneously by equal amounts when manipulating the rheostat as a whole. Fig. 275 shows a three-phase liquid rheostat designed by the author, and which will negotiate currents up to about 30—40 amps. It can be employed either as a "*through*" or "*closed*" rheostat, and consists of three exactly similar flat semicircular-shaped iron troughs or boxes placed side by side in



alignment on a wooden base board, but not in contact with one another. Each is secured to the base board through its flat metal foot, carrying a terminal which therefore makes electrical connection with the box as a whole.

These terminals are clearly seen in Fig. 275. Each box has a semicircular-shaped iron plate, carried by a brass spindle, which passes through bearings of insulating material let into the opposite sides of each box. The ends of each spindle terminate just outside the box in enlarged metal bosses, the successive adjoining pairs being direct coupled mechanically through couplings of insulating material, but are discontinuous electrically.



FIG. 275.

This compound shaft or spindle is rotated with the plates by means of a worm and worm-wheel gearing. Seen to the right-hand end of Fig. 275.

Three other terminals (not seen in the figure) at the back of the rheostat make electrical connection to each section of the spindle, and therefore to each plate through spring strips rubbing on the proper bosses as the spindle is turned.

A solution of washing soda and water of the *same* density is used in each trough, and must not, of course, reach up so high as to make contact with the spindles. Thus when none of the terminals are cross-connected, the rheostat becomes a "through type," but when the three at one side are all joined together, we

have a closed rheostat, suitable for absorbing the load from a generator connected to the remaining three terminals.

It should be remembered that as each of the three sections of this water rheostat must operate equally on turning the shaft, the level of liquid must be the same in each trough in addition to it being of the same density.

### Magnetic Curve Tracer.

This instrument, devised by Prof. Ewing, shows the magnetic quality of iron, steel, or other magnetic metal, by exhibiting the curve which connects the magnetization  $B$  with the magnetizing

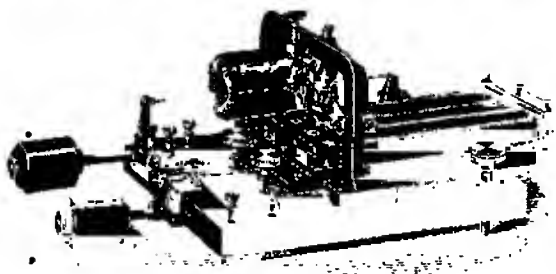


FIG. 276.

force  $H$  in any magnetizing process. The curve is exhibited upon a screen by the spot of light reflected from a mirror, which receives two components of motion. The vertical component is proportional to the magnetization, and the horizontal component to the magnetizing force. The instrument is shown in Fig. 276, and Fig. 277 is a diagram showing the functions of the various parts. The mirror is pivoted upon a single needle-point, which leaves it free to turn both ways, and it is connected by threads to the middle of two stretched wires,  $AA'$  and  $BB'$ , in such a manner that when either of the wires sag the mirror suffers a corresponding deflection. The threads

R R

are kept taut by light springs, the tension of which is adjustable. The wires are stretched in narrow slots, forming gaps in two magnetic circuits, *DD* and *C*. One of these circuits, *DD*, is made up of the iron or steel to be examined, along with suitable pole-pieces and yoke, and the current which passes through the magnetizing coils of this circuit passes also through the stretched wire, *BB*, in the gap of the other magnet. The other magnet is constantly magnetized by a steady current, and a steady current also flows through the stretched wire *AA*. Hence,

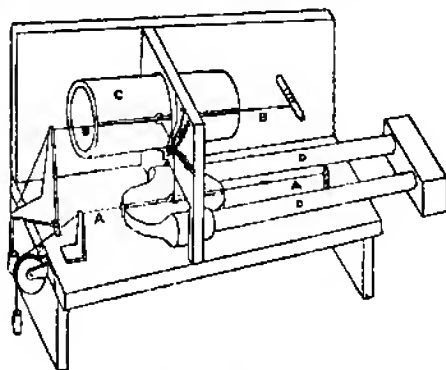


FIG. 277.

when the magnetizing current of *DD* is altered, the wire *BB* sags out or in, and gives horizontal motion to the mirror proportional to the magnetizing force acting on *DD*. And when the magnetism of *DD* is altered, the wire *AA* sags up or down, giving vertical motions to the mirror proportional to the changes of magnetism.

The samples to be tested form the arms of *DD*. They may be solid rods, or rods built up of thin strips, or of wire. The rods supplied with the instrument are of soft sheet-iron, built up of insulated strips, with a net cross-section about 1 in. by  $\frac{1}{2}$  in., and about 18 in. long. In preparing other rods for comparison of magnetic quality, the same dimensions are to

be chosen as those of the standard rods. Clamps are provided at the pole-pieces to allow the rods to be readily inserted and removed.

The same constant current will serve for the wire *AA*, and the magnetizing coil of the tubular magnet *C*. A current of about four amperes will serve well, but more or less may be used, according to the amount of movement which it is desired to give to the mirror. The amplitude of the movements can also be regulated by shifting in or out the weights on the bell-crank levers which keep the stretched wires tight. For high-speed work the wires should be kept very tight, and a small mirror should be used. The magnetizing current must be made to vary in a continuous manner; not by sudden makes and breaks. When these precautions are taken magnetic cycles may be performed so rapidly that the reflected light appears on the screen as a continuous curve. A special commutator is supplied, to allow of rapid but gradual variations and reversal of the magnetizing current. It consists, essentially, of two fixed and two revolving plates of zinc, immersed in a solution of zinc-sulphate.

In ordinary testing it is more convenient to make the magnetic changes occur slowly, and to mark with a pencil the successive positions of the spot on the screen. A sheet of paper on a small drawing board, set up against a wall or other vertical support, is a suitable screen. The source of light may be an ordinary galvanometer lamp, furnished with a pair of cross wires instead of the usual single wire. For high-speed work a small spot of light is necessary, which is obtained by placing a screen with a small hole in it just in front of the lamp. Horizontal and vertical datum lines are marked by moving (by hand) the wires *BB* and *AA* respectively, and marking the path of the spot. A variable resistance is to be inserted in the magnetizing circuit of *DD*, to allow successive points of the magnetizing curve to be obtained: two zinc plates suspended near together in a weak solution of zinc-sulphate, in such a way that they can be more or less deeply immersed, will serve well for this purpose. A rapid commutator is also to be put in this circuit, to allow the specimens under test to be demagnetized by rapid reversals of continuously diminishing magnetizing force, if it is wished to determine the curve of *initial* magnetization. In comparing other samples

with the standard bars, care must be taken to preserve the same scale of  $B$  and of  $H$ , by not changing the constant current in the wire  $AA$  and magnet  $C$ , nor the tension of the stretched wires.

The absolute scale of  $H$  may be calculated, if required, from a knowledge of the number of turns in the winding of the magnet limbs, and that of  $B$  may be found by means of an

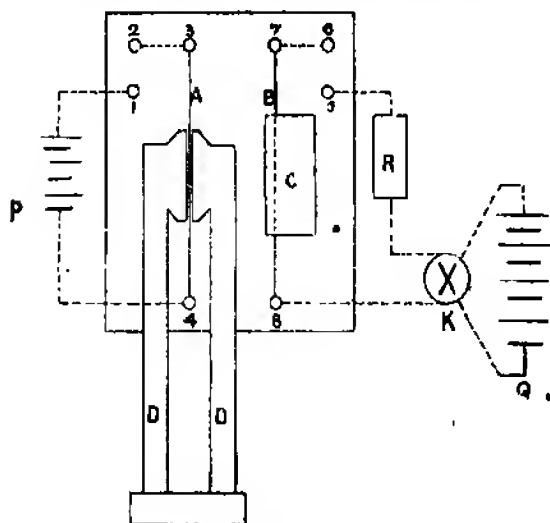


FIG. 278.

auxiliary ballistic galvanometer, by winding an induction coil of a few turns round one or both of the limbs.

Fig. 278 shows the electrical connections with the terminals as they are placed on the slate base of the instrument.

Terminals 1 and 2 are those of the coil which magnetize the tubular magnet  $C$ ; terminals 5 and 6 are those of the main magnet coils on  $DD$ . The constant current is supplied by  $P$ ,

and taking the course 1, 2, 3, 4, passes in series through the magnetizing coil of *C* and the stretched wire *A*. The variable current is supplied by *Q*, through the commutator *K* and adjustable resistance *R*. Taking the course 5, 6, 7, 8, it passes through the main magnetizing coil and the stretched wire *B*. The copper strip which is used to connect 2 with 3 may be put between 1 and 3 instead, 2 and 4 being then the battery terminals in that circuit. The effect of this is to change the general slope of the figure on the screen from right to left or *vice versa*. One of the two arrangements is right when an ordinary screen is used; the other is right when the screen is a piece of tracing paper or ground glass, viewed from behind.

Care should be taken to adjust the instrument so that when a complete cycle of magnetic reversal is performed, the figure on the screen will be symmetrical, with the extremities equidistant from the zero point or origin, which corresponds to the condition of no current in *B* and no magnetism in *DD*. To secure this, see that the stretched wires are as nearly as may be judged in the middle of their respective slots, both vertically and horizontally. Set the mean position of the mirror perpendicular to the pivot needle, by adjusting the needle's position by the screws provided for that purpose. The light springs which keep the connecting threads taut are to be set so that they remain considerably stretched even when the mirror moves to its furthest limit in the direction tending to slacken them.

Fig. 279 is an example of the curves obtained by the instrument shown in Fig. 276. It is the copy of one half of a cyclic curve of reversal, along with the initial curve taken after demagnetizing the specimen by reversal, and also the curve obtained by reapplying the magnetizing current after it had been reduced from its maximum to zero. Owing to the existence of an air gap in the magnetic circuit under test, the diagram is sheared over to the right, and true values of the magnetic force would be found by measuring horizontal distances from some such line as *YY*, instead of from the vertical line. This shearing does not affect the area enclosed by the cyclic curves of reversal, and need not therefore be taken account of in measuring the comparative amounts of energy dissipated by

magnetic reversals in different specimens or in the same specimens with different values of the magnetism.

In addition to its use for determining these areas, for comparing the magnetic qualities of different samples of iron, and for investigating the properties of magnetic curves generally, the instrument may be used as a galvanometer by making the

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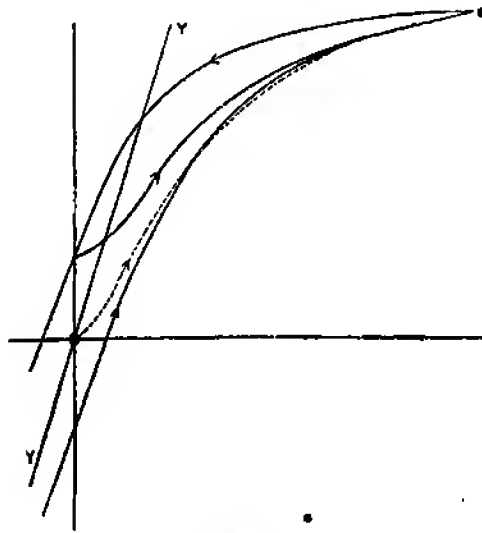


FIG. 274.

current to be measured pass through either of the stretched wires, while the magnet, in the slot of which the wire is stretched, is kept in a constant state of magnetization. This will be found useful in cases where an extremely dead-beat indication is wanted, and by making the spot of light register its position photographically on a moving plate or paper satisfactory records of rapidly fluctuating currents may be obtained.

### The Permeameter.

A useful piece of apparatus, known as the "Permeameter," is illustrated in Fig. 280, by means of which the magnetic quality of different materials can easily and rapidly be found. The method is essentially a workshop one, and the principle of it is due to Professor S. P. Thompson.

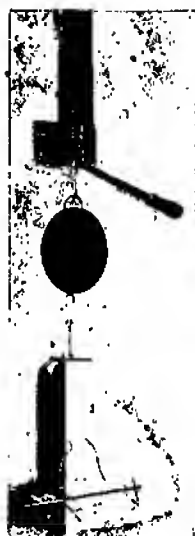


FIG. 280.

The arrangement consists of a somewhat massive hollow rectangular-shaped block of good soft wrought-iron forged to the shape shown. Inside this is a magnetizing solenoid wound on a thin brass tube with thin flanges or ends, its length being just that between the insides of the block ends. The sufficiently long rod of magnetic material to be tested, having its lower end faced quite true, passes freely but closely through the top end of the block, down through the solenoid, and beds on the carefully "faced" inside of the bottom end of the block. The protruding end of the rod has a metal pin

through it, which is caught by a double hook on the lower end of an ordinary spring balance, the top end of which is suspended by a gut cord passing over a fixed pulley and attached to the lever shown. This permeameter is also fitted with an arrangement for testing the specimen ballistically. It consists of a small flat coil fixed to a brass plate, which slides backwards and forwards between guides. The rod passes through this coil and beds as before on the block, at the same time keeping the coil back against the force of two spring strips on the outside of the



block. Immediately the rod is suddenly pulled up the coil flies out, and a circuit joined to its terminals will receive an electromagnetic impulse proportional to the field just broken. In this way the ballistic and traction methods can be made to check one another in the final results obtained.

### Condensers.

Fig. 281 shows a general view of the Kelvin standard air Leyden condenser, and Figs. 282 and 283 a plan and sectional



FIG. 281.

elevation of the same. The instrument is formed by two mutually insulated metallic pieces, which we shall call *A* and *B*, constituting the two systems of the air condenser or Leyden. The systems are composed of parallel plates, each set bound together by four long metal bolts. The two extreme plates of set *A* are circles of much thicker metal than the rest, which are all squares of thin

sheet brass. The set *B* are all squares, the bottom one of which is of much thicker metal than the others, and the plates of this system are *odd* less in number than the plates of system *A*. The four bolts binding together the plates of each system pass through well-fitted holes in the corners of the squares; and the distance from plate to plate of the same set is regulated by annular distance pieces, which are carefully made to fit the bolt, and are made exactly the same in all respects. Each system is bound

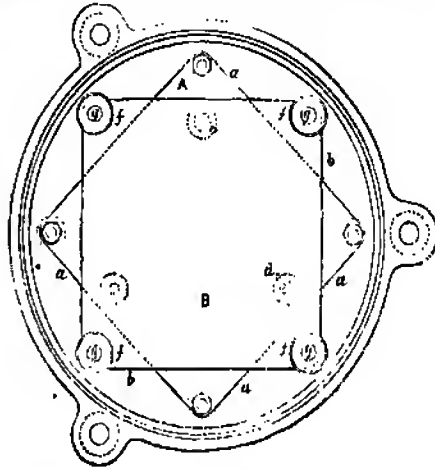


FIG. 282.

firmly together by screwing home nuts on the ends of the bolts, and thus the parallelism and rigidity of the entire set is secured.

The two systems are made up together, so that every plate of *B* is between two plates of *A*, and every plate of *A*, except the two end ones, which only present one face to those of the opposite set, is between two plates of *B*. When the instrument is set up for use, the system *B* rests by means of the well-known "hole,

slot, and plane arrangement,"<sup>1</sup> engraved on the under side of its bottom plate, on three glass columns, which are attached to three metal screws working through the sole-plate of system *A*. These screws can be raised or lowered at pleasure, and by means of a gauge the plates of system *B* can be adjusted to exactly midway between, and parallel to, the plates of system *A*. The complete Leyden stands upon three vulcanite feet attached to the lower side of the sole-plate of system *A*.

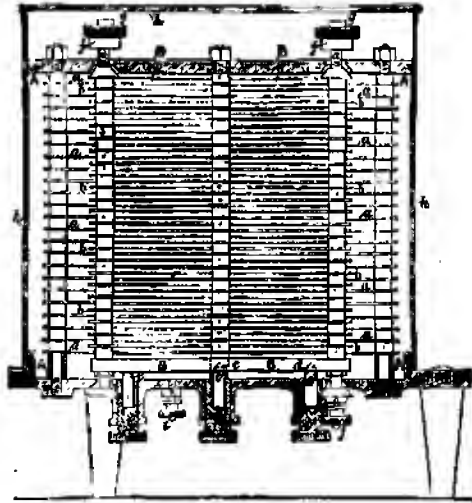


FIG. 283.

In order that the instrument may not be injured in carriage, an arrangement, described as follows, is provided, by which system *B* can be lifted from off the three glass columns and firmly clamped to the top and bottom plates of system *A*.

The bolts fixing the corners of the plates of system *B* are made long enough to pass through wide conical holes cut in the top and

<sup>1</sup> Thomson and Tait's *Natural Philosophy*, § 192, example 3.

bottom plates of system *A*, and the nuts at the top end of the bolts are also conical in form, while conical nuts are also fixed to their lower ends below the base-plate of system *A*. Thumbscrew nuts, *f*, are placed upon the upper ends of the bolts after they pass through the holes in the top plate of system *A*.

When the instrument is set up ready for use, these thumbscrews are turned up against fixed stops, *g*, so as to be well clear of the top plate of system *A*; but when the instrument is packed for carriage, they are screwed down against the plate until the conical nuts mentioned above are drawn up into the conical holes in the top and bottom plates of system *A*; system *B* is thus raised off the glass pillars, and the two systems are securely locked together so as to prevent damage to the instrument.

A dust-tight cylindrical metal case, *h*, which can be easily taken off for inspection, covers the two systems, and fits on to a flange on system *A*. The whole instrument rests on three vulcanite legs attached to the base-plate on system *A*; and two terminals are provided, one, *i*, on the base of system *A*, and the other, *j*, on the end of one of the corner bolts of system *B*.

### Revolving Contact Maker.

This is an arrangement of two contact levers or spring strips, and a revolving ring, whereby electrical contact is made between the two strips *once every revolution* of the ring at a certain particular and definite instant, and place on the circle of revolution depending on the position in which the levers touch the ring. Such an arrangement is necessary when it is desired to take the periodic E.M.F. and current curves of an alternator, and it may be fitted either to the alternator, or to a small single-phase synchronous alternating current motor, to be driven off the particular supply to be sampled. Fig. 284 represents a simple and convenient form of revolving contact maker, designed by the author and fitted to the rotating inductors of an inductor alternator. It consists of a brass frame ring screwed to the alternator portion, and carrying an ebonite ring screwed to it *securely* by set screws through the inner edge of the frame ring. Half the total width of this ebonite ring is turned nearly away and a brass ring slipped on and fixed to the ebonite ring by

screws passing through it sideways. A thin slip of brass (seen just in front of the spring brushes in Fig. 284) is neatly let into the ebonite ring and makes electrical contact with the insulated brass ring only. Two spring strips, insulated from one another, and pressing against the two springs in a line, are carried by a holder capable of being slid along the curve bar seen in the figure



FIG. 284.

and provided with a pointer moving over a scale. Hence any circuit connected to these strips or brushes will be closed once every revolution at an instant in the period which depends on the position of them on the curved rod.

If the toes of the spring brushes are set, one in front of the other, the contact will be more instantaneous, otherwise it will last during the whole time required for the slip contact to pass under the brushes when set level.

### ‘Cradle Absorption Dynamometer.

In Fig. 285 is shown the principle of a typical form of *cradle* absorption dynamometer, suitable for testing the horse-power developed by small motors, but which can also be employed for larger powers up to a certain limit determined by the weight and

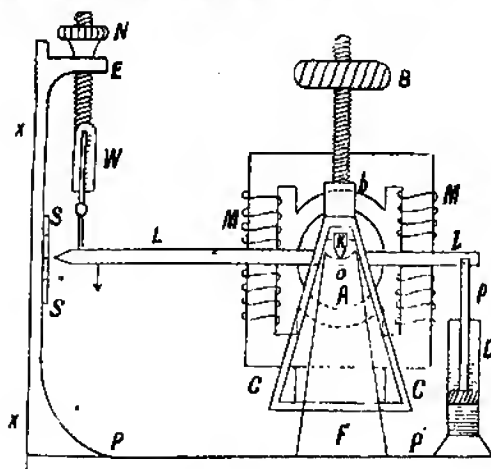


FIG. 285.

size of the motor, and the consequent difficulty in constructing the dynamometer.

It consists of a light framework (*CC*) carrying a small floor or platform at its lower extremities to which the motor *M*, to be tested, is bolted after being packed up so that the centre of its shaft is a line with the points of bearing *O* of the knife edges *K*. The steel plates on which *K* work are at the top of standards *F* carried on a light bed-plate *PP*. A block (*b*) is attached to the

top of the frame *cc*, which carries a screwed bolt on which can travel a heavy balance weight *B*. By raising this weight, therefore, the centre of gravity of *M*, its bed-plate and the cradle *CC* can be raised to the level of *O*. A light lever *L* is fixed to and moves with *CC*, one end being attached to the piston (*p*) of a dash-pot *D* containing some viscous fluid for damping the motions of the cradle *cc*.

The other end is attached to the lower portion of a suitable spring balance *W*, itself supported from a bracket *E*, carried by a standard (*xx*).

The end of the lever *L* moves in front of an index scale *ss*, also carried by *xx*.

The tail rod *l*, together with the piston *p*, are made to, once for all, balance the other part of the beam *L*, so that after *B* is properly adjusted the cradle with its motor would rest in equilibrium in any position if *W* was disconnected from *L*.

The method of procedure is therefore as follows—When the cradle is exactly balanced in the manner indicated above, the spring balance *W* is attached to *L* and the nut *N* screwed up or down so as to bring the lever *L* to the zero of the index scale *SS*. The motor *M* is now connected up so that the field magnets and consequently the cradle tend to turn counter-clockwise. This condition must be arranged for beforehand, and the motor placed in the cradle accordingly, to suit the orthodox direction of rotation of the armature *A*.

A cord is now wrapped once round the motor pulley, and its two ends stretched out horizontally. The motor will thus be made to do work against the friction between the cord and pulley, and the result will be a depression of the end *L* of the beam. Then bring *L* back to zero on the index scale by turning *N* and so raising the balance *W*.

If now *W* = reading of the spring balance in lbs. (say), and *L* = the distance in feet of its point of attachment to the lever, from the centre *O*, then the moment of the force resisting rotation, i. e. the torque  $T = WL$  (pound feet), and if the speed of the armature = *n* revs. per sec., the angular velocity  $\omega = 2\pi n$ .

Hence the work done per sec. =  $\omega T$ , and the horse-power developed =  $\frac{\omega T}{550}$ , since 1 H.P. = 550 ft. lbs. per sec.

### Horse-Power Transmission Dynamometer.

When the mechanical power required to drive some particular machine, as for instance a dynamo, is desired to be known, it can be obtained by means of a *transmission* dynamometer. This is an appliance for measuring mechanical power without absorbing any of it, as distinguished from the *absorption* dynamometer which measures the power by wasting it all. There are two main classes of the transmission instrument, namely, those for measuring the power transmitted directly through a shaft, and secondly, those for measuring the power transmitted by a belt.

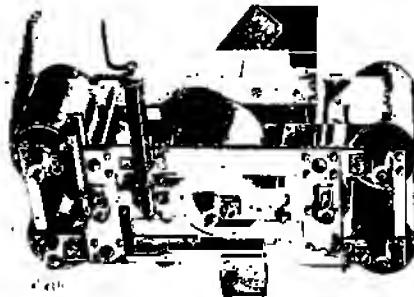


FIG. 286.

Fig. 286 represents the general view, and Fig. 287 the symmetrical side elevation, of one belonging to the latter class and made by Messrs. Siemens Bros. and Co. of London. By means of it the difference in tension ( $T-t$ ) between the driving (i. e. the tight) and slack sides of the belt can be read off directly in pounds, and which is the only one troublesome factor required of the horse-power to be measured.

Referring to Fig. 287, this Siemens transmission dynamometer consists of four similar roller pulleys, running in bearings carried at the four corners of a light but strong iron framework ( $AK$ ). Three other roller pulleys run in bearings carried by the arm or



frame (*A*), which is capable of oscillating about a fulcrum *F* on part of the main frame. The centre pulley *P* is really the actuating part of the dynamometer, the remaining six, namely *p* and *g*, merely acting in a sense as guide pulleys for the belt, the "tight" or driving side of which is *TT* and the slack side *tt*. The left-hand end of the arm or frame *A* has attached to it a link (*l*), which actuates a lever pointer *L* capable of moving on a fulcrum (*f*) over an index scale *C*, and carrying a balance weight *W* for the purpose of balancing the arm *A* with its fittings, etc. *D* is a dash-pot to steady, what would otherwise be, the jerky

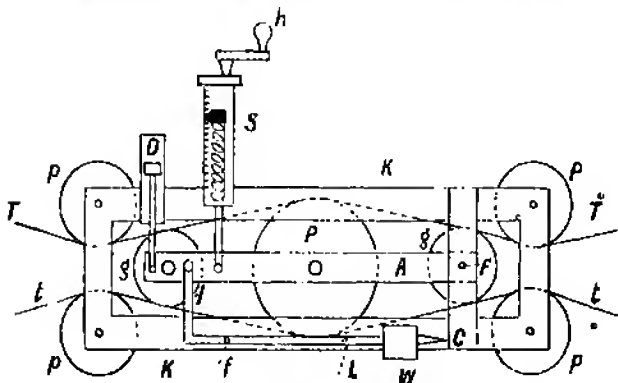


FIG. 287.

movements of *A*. A strong, spiral spring *S*, capable of being extended by turning a handle (*h*), is attached to the left-hand part of *A*. The action of the dynamometer will now be fairly obvious, and is as follows—

The tight side of the belt *TT* tends to force down the left-hand end of *A* against the smaller upward force of the slack side *tt*, this causes *L* to turn about *f* in a counter-clockwise direction; but *L* is now brought back to zero by turning (*h*), and when this is the case, the force exerted by *S* just balances and is equal to the difference in tension ( $T-t$ ), and is read off on the scale over

which the pointer, attached to the top end of  $S$ , moves. Thus according as to whether  $S$  is calibrated in lbs. or kilograms so the quantity  $(T-t)$  is read off in these units. If now  $V$  = velocity of the belt in ft. per min., as obtained from the noted speed of the driven pulley ( $N$ ) revs. per min. and its diameter  $d$  (ft.), then  $V = \pi dN$ , and the H.P. transmitted =  $\frac{\pi dN(T-t)}{33,000}$ .

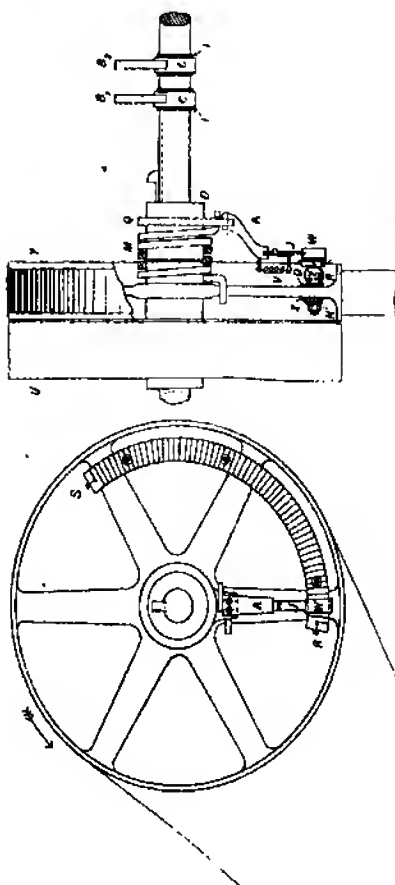
### The Measurement of Power transmitted by Belts.

In the case where it is desired to measure the mechanical power absorbed by some particular machine, such as, for instance, a dynamo feeding a lamp circuit, or any other kind of machine driven by means of belting, the use of a form of Prony brake or other kind of *absorption* dynamometer is inadmissible, owing to the well-known fact that such an appliance wastes all the power which it measures. In this case a transmission dynamometer has to be resorted to, of which there are several different forms, some remaining permanently in position, so as to be capable of indicating at any moment the power transmitted, others being temporarily erected in position for the tests; as, for instance, the Siemens-Hefner-Alteneck belt transmission dynamometer. It is, however, manifestly more convenient to have a permanent arrangement, and the general principle of this type is to connect the driving pulley, which is loose on its shaft, by three or more helical springs, to a fixed collar or boss keyed to the shaft, and then to measure in some convenient way the "angular advance" of the shaft relatively to the pulley, due to the axial extension of the springs. This, as is well known, gives a measure of the power transmitted. Hitherto, however, the arrangements for observing this angular advance have not proved very satisfactory.

By the kind permission of the proprietors of *The Mechanical Engineer*, the author is enabled to give a reprint here of an article written by him in that journal of March 19, 1898, on a neat form of spring transmission dynamometer the recording arrangement of

which was devised by Professor W. Stroud some little time back, and, is in use in the electrical engineering laboratories at the University, Leeds. It is accurate and extremely simple both in principle and working, and can be easily fitted to any shaft and kept permanently in position. It has the distinct advantage that the measurement of angular advance is solely an electrical one, and can consequently be obtained with considerable accuracy.

Fig. 288 shows an end elevation, and Fig. 289 a side elevation, of the arrangement, with the lower part of the driving pulley (*y*) cut away. It is on a counter-shaft, and rotates in the direction of the arrow (Fig. 288), driving a machine. It consists of a boss *O*, which is keyed to the shaft, and is provided with a flange *Q*, having an extension at one part of its circumference in the form of a short projection or arm. One end of the steel-driving spring *M*, which is of square cross-section, is bent so as to partly embrace this arm and be driven by it; the other end is similarly bent, only in the opposite sense, to partly embrace one arm of *y*, which is loose on the shaft, and drive it. Only these two bent ends of *M* are shown in Fig. 289, two turns being cut away, as shown, in which is a part sectional elevation about a vertical diameter through shaft centre. The bolt can be thrown on to a loose pulley (*u*) by a fork not shown. To the short projection on the flange *Q* (Fig. 289) is bolted a light but strong bent arm *A* into a saw-cut, in the end of which are sweated the ends of two rigid strips of brass side by side. The right-hand one ends in a hinge, which carries a similar strip *J*, into the side of which is fixed a rigid pin, which passes freely through a slot cut in the end of the left-hand fixed strip. This latter is merely for the purpose of preventing *J* being pulled too far towards the pulley (*y*) by the spiral spring *V*. The hinged strip *J* carries at its end a light brass block *W*, to which is attached, but electrically insulated from it by means of ebonite or vulcanized fibre (*D*), a rounded brass contact block *T*. This makes electrical contact with a curved resistance frame *RS*, consisting of a curved piece of wood of somewhat smaller radius than the pulley rim, and of section something similar to that shown at *R* (Fig. 289). It embraces an angle of about 120 deg., and is provided with shallow saw-cuts on the inner and outer peripheries. Into these are



pressed the turns of wire with which it is wound, consisting in the present instance of between 280 and 300 turns of No. 18 or No. 20 B. W. G. platinoid wire, double silk covered, the ends being led out to brass terminal blocks at the extremities *R* and *S*. The arrangement is securely clasped to the arms of the pulley by the counter-sunk bolts *N*, which pass through a similarly curved piece of wood of section shown at *X* (Fig. 289), placed on the other side of the arms. A thin piece of soft insulating material (*D*) is interposed between these latter and *R* to prevent some of the turns of wire being short-circuited, and thereby rendered useless, or damaged by pressure against the arms. The turns of wire are bared of their silk insulation, along the line on which *T* makes contact with them between *R* and *S*. Two thin strips of

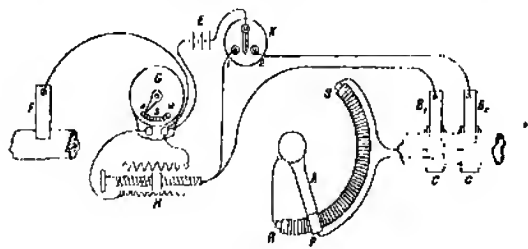


FIG. 290.

vulcanite *I I* are bent completely round the shaft, and over them are stretched two thin strips of brass *CC*, the ends of each being soldered together so as to form continuous rings, against which, as they rotate, press two small copper gauze brushes *B<sub>1</sub>B<sub>2</sub>*. It now remains to describe the method of indicating the angular advance, and so the measure of power transmitted. This is accomplished wholly electrically, a symbolical diagram of connections being shown in Figs. 290 and 291, corresponding parts being lettered alike. The brass rings *CC* are permanently and electrically connected by insulated copper wires to *S* and *T*, as shown, the shaft and arm *A* being depicted as taking up a position *P* on *RS* in advance of the pulley (*Y*). *R* is in electric connection with *Y*, and therefore with the shaft. *N* is a fixed brush, which

simply rubs on and makes contact with the shaft.  $K$  is a two-way key;  $E$  a battery of about three cells, preferably secondaries;  $G$  is a sensitive galvanometer or potential difference indicator, as dead beat as possible, and preferably of the moving coil or D'Arsonval type, in order that, firstly, its deflections may be directly proportional to the potential difference at its terminals; and, secondly, that by winding the moving coil on a light but broad aluminium frame, it can be made very dead beat.  $G$  is provided with a "constant total current shunt," shown symbolically at  $H$  (Fig. 290), which is for the purpose of adjusting the sensibility of  $G$ , to which it is shunted without altering the gross resistance of the combination, and therefore the P.D. between the two points to which it is applied.

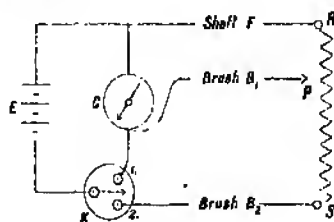


FIG. 291.

The principle of action of  $H$  is merely that the screw, fixed as regards end play, when turned, actuates the contact block, rubbing between the top and bottom resistances, which are suitably proportioned to one another and to the galvanometer as well. The resistance between the terminals of the combination should be at least 20 times that of  $RN$ .

In starting the calibration, switch the lever of key ( $K$ ) on to stop 1 (Figs. 290 and 291).  $G$  is then directly across  $E$ , and the number of cells together with the sensitiveness of  $G$  (by using  $H$ ) should be adjusted to give a full scale deflection. This must always be re-obtained before starting subsequent tests. Now, switch to 2 on  $K$ , so completing the main circuit by way of  $P$ , shaft,  $R$ ,  $S$ ,  $B_2$ ,  $K$ ,  $E$ , and back to  $F$ . A certain current will flow,

depending, of course, on the total resistance and pressure at  $E$ , and for this current a definite P.D. will exist between  $R$  and  $S$ , and also between  $R$  and  $P$ , causing a deflection on  $G$ , as shown. The calibration is now finally effected by hanging known dead weights from the face of pulley ( $F$ ), thereby twisting up  $M$  (Fig. 283), and noting the corresponding deflections on  $G$ . The mean nett pull with any particular dead weight will best be obtained by taking the mean of two readings on  $G$ , corresponding to the two extreme positions of equilibrium of the pulley, this latter being helped to take up these positions.

Fig. 292 shows two calibration curves  $A$  and  $B$ , for two totally distinct transmission dynamometers of this type, every detail in each being precisely the same with the exception of the springs  $M$ , being different as regards number of spirals and area of cross-section of these only. A few details about these may be worthy of note. The spring of the dynamometer giving curve  $A$  (Fig. 292) consists of three complete turns of tempered steel of normal internal diameter =  $6\frac{1}{8}$  in., and square cross-section =  $\frac{1}{2}$  in.  $\times$   $\frac{1}{2}$  in. A pull = weight of 50 lbs. at the pulley face wound it up tight on the surface of the bosses  $5\frac{1}{2}$  in. diameter, giving a deflection on  $G$  of 9.1 (10 being full). This result is clearly shown by the bending of the curve at the top part. The spring of the dynamometer giving curve  $B$  consists of five complete turns of same diameter, but square cross-section =  $\frac{1}{2}$  in.  $\times$   $\frac{1}{2}$  in. Its internal diameter was approximately  $\frac{1}{4}$  in. in excess of that of its bosses ( $5\frac{1}{2}$  in.), for the largest weight used (180 lbs.). Hence, not being tight up, there is no bending of the curve  $B$ . The turns of both springs nearly touch.

It may now be useful to note, with regard to the design of such a helical spring, the relation that subsists between the pull of the weight at the pulley face, the decrease of the diameter of the spiral, and the angular deflection of one end of the spring in a plane perpendicular to its axis, represented by the position or the point of contact  $P$  (Figs. 290 and 291) on  $RS$ . Let  $W$  = dead weight applied, i.e. the tangential force at the circumference of the pulley of radius  $R$ .

Then the moment ( $M$ ) of the twisting couple in a plane perpendicular to the axis of the spring is  $M = WR$ . If the coils are quite flat, and their planes at right angles to this axis, there will

be no torsion in the spring itself, and it will be wholly subjected to a bending action due to  $M$ .

If  $r_0$  = mean radius of the helix before  $W$  is applied,

$r$  = mean radius of the helix after  $W$  is applied,

and  $\theta$  = angle of twist, i. e. the angle through which it is wound up. Then, since the moment of the twisting couple must just balance that due to the elastic force of the spring when the arm  $A$  (Fig 290) has come to some steady position  $P$  on  $RS$ , we have

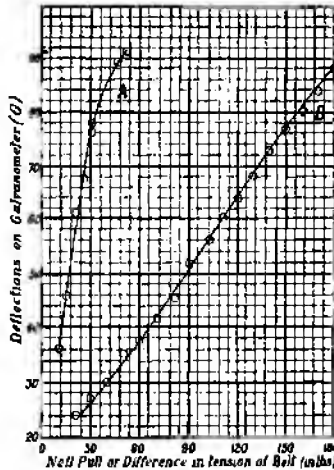


FIG. 292.

$M = EI \left( \frac{1}{r} - \frac{1}{r_0} \right) = EI \frac{\theta}{l} = WR$ , where  $l$  = length of the spring and  $EI$  represents the flexural rigidity of the material of which the spring is made.

$E$  being the modulus of elasticity for the material, i. e. tempered steel.

$I$  being the moment of inertia of the section of the material, i. e. for a square.

In the present case, therefore, for square section  $I = \frac{b^4}{12}$  where



( $b$ ) = length of a side of that square section. Substituting in the above equation we have

$$WR = \frac{Eh}{12} \left( \frac{1}{r} - \frac{1}{r_0} \right) = \frac{Eh^3 \theta}{12 \cdot l}$$

from which it can be seen that for a given pulley, material of the spring, and angle of twist,  $W \propto \frac{(\text{sectional area of spring})^3}{\text{length}}$ .

We have also that the deflection or distance through which  $W$  acts =  $R\theta$ .

Writing the first equation in another form, we get an expression for the amount of coiling of the spring for a particular weight  $W$ .

$$\text{Thus } r = \frac{EI r_0}{r_0 WR + EI} = \frac{Er_0 b^4}{12 r_0^2 WR + E b^4}$$

$W$  is evidently the nett pull on the circumference of pulley, and if  $T$  = tension (in lbs.) of the tight or driving side of the belt, and  $t$  = tension (in lbs.) of the slack side; then  $W = (T - t)$  = nett pull of belt in pounds, which is one factor of the horse-power transmitted. Also, if the pulley of the machine driven by ( $Y$ ) is of radius ( $f$ ) ft. and makes ( $n$ ) revolutions per minute, then, for no slipping of the belt, velocity of belt ( $v$ ) =  $(2\pi fn)$  ft. per minute, and horse-power

$$\text{transmitted} = \frac{V(T - t)}{33,000} = \frac{2\pi fn (T - t)}{33,000} = H_2$$

If the driven machine be a dynamo developing  $A$  amperes of current at a pressure of  $V$  volts on the external circuit at that speed, then the useful horse-power developed  $H_1 = \frac{AV}{746}$

Its commercial or nett efficiency is therefore =  $\frac{H_1}{H_2} \times 100$  per cent.

In conclusion, it may be mentioned that the dynamometer forms a simple and accurate means of measuring the horse-power transmitted to any machine, and works very satisfactorily provided there is no skidding of the belts, and also that the spring ( $V$ ) (Fig. 289) exerts sufficient tension on  $J$  to give a good reliable contact between the contact piece ( $T$ ), to which the brass ring under  $B_1$  is electrically attached, and the curved resistance  $RS$ .

### Absorption Dynamometer.

Fig. 293 illustrates an absorption dynamometer which is a modification of a Prony brake for making brake tests of the horse-power developed by electromotors. One great trouble in-



FIG. 293.

herent in all such tests is the high speed (relatively to other prime movers) at which these machines run, especially small ones. This tends to cause a jerkiness of the brake and trouble conse-

quently in reading the indications of the various parts. In Fig. 293, three plies of cord make a half-lap over the top side of the brake pulley, at one side supporting a scale pan, and at the other (the nearest to the observer looking at the figure) being attached to a single cord passing round a nearly frictionless pulley and hanging from the lower end of the spring-balance seen at the top of the illustration. This double bend of the cord is merely for convenience in having the balance in a position where it can be read easily. The three plies of cord over the pulley are kept in position by light brake blocks as shown. Thus the weights in the pan will represent the tension on the tight side, and the reading of the balance that on the slack side, so that their difference gives the nett load on the brake. The brake pulley shown is a special form of box pulley devised by the author, and water-cooled by an inlet or outlet pipe passing through a central opening.

Another form of Prony brake, giving excellent results with small motors from about  $\frac{1}{4}$  B.H.P. upwards at speeds up to

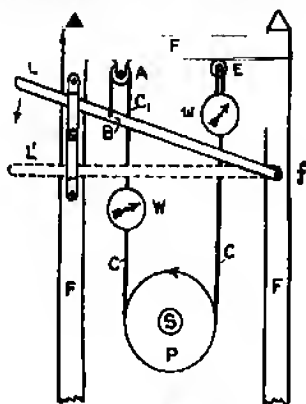


FIG. 294.

2,000 revs. per min., is shown diagrammatically in Fig. 294, and consists of a light cast-iron flanged pulley *P* keyed to the shaft *S* of the motor to be tested and rotating truly on it. A light

framework *FFF* carries an eyelet *E*, from which hangs a spring balance *w*. From the lower end of *w* a pliable cord passes  $1\frac{1}{2}$  times round *P* and is attached to another spring balance *W*. From the upper end of *W* a cord *C*, passes round a small grooved pulley *A* (supported from *F*) to a fixed point *B* on an iron lever *L*. This lever is pivoted at *f* and is capable of moving in a guide *G* between the limits *L* and *L*<sup>1</sup>. If *P* rotates counter-clockwise as shown, (*W*) will read the tension on the *tight* side, and (*w*) that on the *slack* side, of the brake rope *C*, so that (*W* - *w*) = nett pull in lbs., and if (*r*) = radius of (pulley face +  $\frac{1}{2}$  diam. of *C*) in feet, then the torque exerted = (*W* - *w*) *r* lb.-ft., and the B.H.P. =  $\frac{2\pi nr(W-w)}{33,000}$ , where *n* = speed of *P* in revs. per min.

The ranges of *W* and *w* may be as 3 : 1, and if the face of *P* rotates quite *truly*, the deflections of *w* and *W* are quite steady and easy to read. The hand pressure on *L* can be both easily and very gradually applied, and when released, the weight of *W* raises *L* and releases *P* from the pressure of *CC* automatically—a feature of some value in preserving the rope, and a convenience in motors which do not race on removal of load.

### Eddy Current Brake.

One of the most convenient methods of measuring the brake horse-power of electro-motors, petrol, and other motors, especially when the speed is high, is by means of an electro-magnetic or eddy-current brake. While the principle has been used in commercial work to an enormous extent in light apparatus, e.g. in electricity meters and instruments, so far as the author is aware, Messrs. Morris & Lister of Charlton Works, Coventry, were the first to patent and put on the market a form suitable for absorbing and measuring the B.H.P. of electro-motors, etc. One of these, used by the author for many years, gave excellent results. Unfortunately the firm have ceased to make them, and it is therefore of little use to describe this particular form. The general principle underlying the construction and action of all such brakes will readily be understood from Fig. 295.

A cylindrical ring  $C$  of copper is fixed securely to the outer surface of an iron drum  $I$  keyed to the shaft ( $S$ ) of the motor, and rotates in a multipolar electro-magnetic field system  $M$ .

Fixed to  $I$ , and in a line passing through the centre of  $S$ , is a light graduated lever  $L$ , from two to five feet from tip to shaft centre, and made of thin aluminium or steel tube. This moves opposite a fixed index scale  $B$  between stops  $A$ , and carries a light slider  $D$  from which known weights  $W$  can be hung. A small sliding weight  $w$ , which can be clamped by a set screw on a light tail rod ( $f$ ), serves to counterbalance the weight of  $L$  and  $D$ . A direct current, flowing through the field coils of  $M$ , produces a powerful multipolar magnetic field through the gap between  $I$  and the poles in which  $C$  rotates. E.M.F.'s are therefore induced in  $C$ , causing eddy or Foucault currents

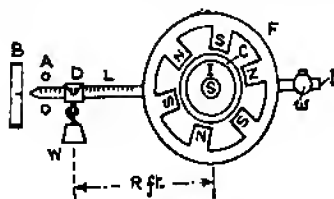


FIG. 295.

to flow in  $C$ , which oppose the driving source, and the output of the motor is thus expended in heating  $C$ . The strength of these currents, and hence the B.H.P. of the motor absorbed, depends on the strength of field, which is readily controlled by means of a rheostat in the exciting circuit.

The force or torque resulting from the interaction between field and currents in  $C$  tends to drag the floating field system  $I$  round, and this is opposed and balanced by a gravitational force due to the weighted lever  $L$ .

When a position of  $D$  (at a radius  $R$  feet from the shaft centre) in conjunction with the adjustment of excitation, is found, such that the above opposing forces balance, the lever  $L$  will float between the stops  $A$ . The torque or turning moment (in lb.-ft.) exerted by the motor then  $= WR$  and its B.H.P. =

$\frac{2\pi RnV}{33,000}$  at a speed of ( $n$ ) revs. per min.

The field frame  $F$  can either be carried by a separate support, giving freedom of oscillation, or on a sleeve by the motor spindle itself; but even in this method the weight due to the whole brake is considerably less than the pull due to a belt drive. For example, a 3-H.P. (continuous rating) size, made by Messrs. Morris & Lister, and running at 1,500 revs. per min., weighed 45 lbs., while a 35-H.P. (continuous rating) brake at 250 revs. per min. weighed 250 lbs. complete. With a suitable provision in the design for ventilation, such brakes could be used for temperature load tests, but these are more economically effected by one or other of the well-known regenerative methods. A brake suitable for a certain H.P. and speed (intermittent rating) will, of course, absorb smaller powers for longer periods, or one for continuous rating larger powers, up to 100% for short periods. Higher speeds require smaller brakes. Anyone who has used this class of brake will have realized the many practical advantages it possesses over other kinds of absorption brakes, particularly in the matter of sensitiveness, control, smoothness of operation, and accuracy in repeating readings, to say nothing about the absence of wear, burnt blocks, bands, and rope and water-cooling arrangements.

### Soames Motor Testing Brake.

This appliance belongs to the class of mechanical power measurers known as absorption dynamometers, and is a modified form of Prony brake made by Messrs. Nalder Bros. and Co. It is of extremely simple construction, and gives perfectly definite weighing of the torque on the pulley under test against ordinary dead weights. It consists of a steel lever working on knife edges, which can be raised or lowered by the hand-wheel at the top of the brake. Holes are drilled in the lever at equal distances from the centre, corresponding to the ordinary sizes of pulley in use.

The centre of the brake is placed over the centre of the pulley, and from the two holes corresponding to the diameter of the pulley under test is suspended a piece of webbing, which passes round the pulley as in the diagram, Fig. 296.

When the pulley is running, a weight, say from  $\frac{1}{2}$  to 30 lbs., is suspended on the end of the arm as shown.

The whole is then raised by turning the hand-wheel, tightening the belt on the pulley until sufficient friction is put on the belt to raise the arm to a horizontal position and keep it floating there; the speed of the pulley being taken at the same time.

The weight is hung at either of the two holes at the end of the bar marked respectively H.P.  $K = 4000$  and Watts  $K' = \frac{1}{6}$ , the one



FIG. 286.

hole giving H.P. direct by multiplying weight in lbs. by revolutions per minute, and dividing by 4000, the other hole similarly giving Watts direct by dividing by 6.

The constant for H.P. is  $2\pi L \div 33,000$ ,  $L$  being the distance of the weight from the centre.

The size of the pulley does not enter into the equation, so long as the distance between the holes in the arm is equal to its diameter.

The band *must*, in all cases, be hung from two holes equidistant from the centre.

The pulley should be perfectly smooth and flat, and it is convenient but not necessary to have it flanged.

No lubricant is generally required, but a little black-lead may be applied if necessary; *no oil*.

This brake is extremely accurate, and every reading can be repeated with certainty, each one not taking more than ten seconds at the outside.



# TABLES OF CONSTANTS, LOGARITHMS, ETC.

## Standards for Copper Conductors.

*(Adapted by the Electrical Standards Committee representing the General Post Office, Institution of Electrical Engineers, and all the leading cable manufacturers of Great Britain.) Revised March 1910.*

A wire 1 metre long, weighing 1 gramme, at 60° F. (15·6° C.) has Matthiessen's value of resistance—

0·1539 standard ohms for hard-drawn, high conductivity commercial copper.

0·150822 standard ohms for annealed, high conductivity commercial copper.

These figures at 60° F. being calculated from 0·1469 per metre-gramme for hard-drawn, and 0·1440 for annealed copper at 32° F. by Matthiessen's formula—

$$R_t = \frac{R_{32}}{1 - 0\cdot00215096(t - 32) + 0\cdot00000278(t - 32)^2}$$

Hard-drawn copper is defined as that which will not elongate more than 1% without fracture.

Copper is taken as weighing 555 lbs. per cubic foot at 60° F., and its corresponding specific gravity = 8·912.

The average temperature coefficient is = 0·00238 per degree F. A lay of 20 times the pitch diameter is taken as the standard for calculating all tables.

The resistance and weight of conductors is calculated from the actual length of wire, or 1·01226 times the length of the cable for all except the centre wire.

Maximum variation of resistance or weight of any wire allowing for losses in manufacture is 2%.

An allowance of 1% increased resistance as calculated from the diameter is permissible on all tinned copper between Nos. 22 and 12 gauges inclusive.

The following tables of figures are deduced from the above constants—

TABLE XV.

COPPER WEIGHING 555 LBS. PER CUBIC FOOT AT 60° F.

Bolt Wires.	Resistance in Standard Ohms of high conductivity Commercial Copper.	
	Annealed.	Hard-Drawn.
Resistance per cubic inch	0.0000066738	0.00000681337
" " " cm.	0.00000169639	0.00000173054
" " of 100 ins. weighing 100 grains.	0.150158	0.153131
Resistance per mile	0.042517 $\div$ area in $\square$ "	0.0431689 $\div$ area in $\square$ "
" per yard	0.000024044 $\div$ "	0.0000245277 $\div$ "
" per mil. foot	10.2044	10.4099

Weight per mil. . . . .  $2.0350 \times$  area in  $\square$ "

" " yard . . . . .  $11.5625 \times$  "

The following table refers to copper cables with a lay = 20 times the pitch diameter.

TABLE XVI.

Cable.	Resistance in Standard Ohms.	Weight.
3-Strand	0.83742 $\times r$	3.03678 $\times w$
4- "	0.253065 $\times r$	4.04904 $\times w$
7- "	0.1443557 $\times r$	7.07356 $\times w$
12- "	0.094355 $\times r$	12.1471 $\times w$
19- "	0.0532424 $\times r$	19.2207 $\times w$
37- "	0.0278493 $\times r$	37.4314 $\times w$
61- "	0.0165911 $\times r$	61.7356 $\times w$
91- "	0.0111222 $\times r$	92.1034 $\times w$

where  $r$  = the resistance of each wire,

and  $w$  = " weight

The resistance of a cable being equal to the resistance in parallel of the wires.

T T

## International Standards of Resistance for Copper.

*Extract from the British Engineering Standards Association Report, No. 7, July 1919.*

1. The following standards, fixed by the International Electro-Technical Commission, have been taken as normal values for standard annealed copper:—

(i) At a temperature of 20° C. the resistance of a wire of standard annealed copper, one metre in length and of a uniform section of one square millimetre, is 1/58 ohm (0.017241 . . . ohm).

(ii) At a temperature of 20° C. the density of standard annealed copper is 8.89 grammes per cubic centimetre.

(iii) At a temperature of 20° C. the "constant-mass" temperature coefficient of resistance of standard annealed copper, measured between two potential points rigidly fixed to the wire, is—

$$0.00393 = 1/254.45 \text{ . . . per degree Cent.}$$

(iv) As a consequence it follows from (i) and (ii) that at a temperature of 20° C. the resistance of a wire of standard annealed copper of uniform section, one metre in length and weighing one gramme, is—

$$(1/58) \times 8.89 = 0.15328 \text{ ohm.}$$

### COEFFICIENT OF LINEAR EXPANSION OF STANDARD ANNEALED COPPER.

2. The coefficient of linear expansion of standard annealed copper between 60° F. (15.6° C.) and 68° F. (20° C.) has been taken as—

$$0.00000944 \text{ per } 1^{\circ} \text{ F. (0.0000170 per } 1^{\circ} \text{ C.).}$$

### DENSITY OF STANDARD ANNEALED COPPER AT 60° F.

3. The density of standard annealed copper at a temperature of 60° F. has been taken as 8.892015, and the weight per one cubic foot of copper as 555.1108 lbs.

### RESISTANCE OF A SOLID CONDUCTOR AT 60° F.

4. For the purpose of calculating the tables, the resistance of a solid conductor of standard annealed copper at 60° F., 1000 yards in length and of uniform cross-sectional area of one square inch, has been taken as 0.0240079 ohm.

TABLE XVII.

RELATION BETWEEN E.M.F. AND TEMPERATURE OF THE CLARK STANDARD CELL—MADE ACCORDING TO REGULATIONS, OF THE CARHART-CLARK, AND OF THE WESTON CADMIUM STANDARD CELLS (see pp. 13 and 17).

Temperature °C.	E.M.F. in Legal Volts.			Temperature °C.	E.M.F. in Legal Volts.		
	Clark.	Carhart-Clark.	Weston Cadmium.		Clark.	Carhart-Clark.	Weston Cadmium.
4	1.4561	1.4595	1.01893	16	1.4559	1.4585	1.01846
6	1.4560	1.4590	91	17	1.4558	1.4580	42
8	1.4559	1.4585	87	18	1.4507	1.4525	84
7	1.4558	1.4580	85	19	1.4500	1.4500	84
8	1.4517	1.4575	79	20	1.4505	1.4515	80
9	1.4500	1.4570	75	21	1.4574	1.4510	76
10	1.4505	1.4565	71	22	1.4563	1.4506	72
11	1.4504	1.4560	66	23	1.4553	1.4500	72
12	1.4515	1.4555	62	24	1.4541	1.4505	74
13	1.4516	1.4550	58	25	1.4540	1.4500	70
14	1.4521	1.4545	54	26	1.4519	1.4505	65
15	1.4540	1.4540	1.01890	27	1.4508	1.4500	1.01872

TABLE XVIII.

RELATION BETWEEN PRACTICAL AND C.G.S. (ABSOLUTE) UNITS.

	Practical units.	Absolute C.G.S. units.		Dimensions.	
		Electro-magnetic.	Electrostatic.	Electrostatic.	Electro-magnetic.
Quantity	1 coulomb	$10^{-1}$	$9 \times 10^{-1} = 9 \times 10^9$	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1}$	$M^{\frac{1}{2}} L^{\frac{1}{2}}$
Current	1 ampere	$10^{-1}$	$9 \times 10^{-1} = 9 \times 10^9$	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-2}$	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1}$
Potential	1 volt	$10^8$	$10^9 \div 9 = \frac{1}{9} \times 10^{-9}$	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1}$	$M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-2}$
Resistance	1 ohm	$10^9$	$9 \times 10^9 = \frac{1}{9} \times 10^{-11}$	$L^{-1} T$	$LT^{-1}$
Capacity	1 farad	$10^{-9}$	$9 \times 10^{-9} = 9 \times 10^{11}$	$L$	$L^{-1} T^2$
Self-induction	1 henry	$10^9$	—	—	$L$
Mutual induction	1 henry	$10^9$	—	—	$L$
Power	1 watt	$10^7$	—	—	$ML^{\frac{1}{2}} T^{-2}$
Work	1 joule	$10^7$	—	—	$ML^{\frac{1}{2}} T^{-2}$
Induction	1 weber	$10^8$	$9 \times 10^{10}$	—	$M^{\frac{1}{2}} L^{-\frac{1}{2}} T^{-1}$

$v = \text{velocity of light} = 3 \times 10^{10}$  cms. per second.

TABLE XIX.  
ELECTRO-CHEMICAL EQUIVALENTS, SPECIFIC GRAVITIES, ETC.

Metal.	Atomic weight.	Chemical equivalent = at. wt. valency	Electro-chemical equivalent, grains per coulomb.	Weight in grains per hour deposited by 1 amp.	Specific gravity in grams per cub. cm.
Aluminum . .	27.0	9.0	0.00009917	0.3584	2.67
Copper (monad) .	63.5	63.5	0.0006735	2.866	8.92
Gold (dyad) . .	196.7	98.3	0.0003367	1.187	19.3
Iron (dyad) . .	55.8	27.9	0.0003806	1.410	7.45
Lead . . . . .	206.4	103.2	0.0001714	0.6371	11.4
Nickel . . . . .	58.6	29.3	0.0003038	1.094	8.5
Silver . . . . .	108	108	0.001190	4.249	10.57
Tin (dyad) . . .	117.8	58.9	0.0001777	0.6488	7.3
Zinc . . . . .	65	32.5	0.0003644	1.212	7.15
Hydrogen . . . .	1	1	0.0001043	0.3738	0.000896

TABLE XX.  
TEMPERATURE COEFFICIENTS AND SPECIFIC RESISTANCES OF PURE METALS AND ALLOYS, DETERMINED BY PROFESSORS J. A. FLEMING AND J. DEWAR.

Metals, pure, soft, and annealed.	Specific resistance, $\rho$ , in microhms. per c.c. at 0° C.	Mean temperature coefficient, $\alpha$ , between 0° and 100° C.	Alloys, usual proportions.	Specific resistance, $\rho$ , in microhms. per c.c. at 0° C.	Temperature coefficient, $\alpha$ , at 16° C.
Platinum . .	10.917	0.002600	Platinum-silver . .	21.582	0.00248
Gold . . . .	2.197	0.003770	"    Iridium . .	80.896	0.003411
Palladium . .	10.410	0.003840	"    Rhodium . .	21.142	0.00148
Silver . . . .	1.468	0.004000	Gold-silver . . . .	6.980	0.00124
Copper . . . .	1.681	0.004280	Manganese steel . .	67.143	0.00127
Aluminum . .	2.682	0.004860	Nickel steel . . . .	20.492	0.00201
Iron . . . . .	9.568	0.006460	German silver . . .	29.883	0.00273
Nickel . . . .	12.928	0.006280	Platinoxal . . . .	41.781	0.00310
Tin . . . . .	13.048	0.004400	Manganin . . . . .	46.075	0.00000
Magnesium . .	4.635	0.003810	Silver-cadmium . .	2.064	0.00285
Zinc . . . . .	5.751	0.004060	Aluminum-silver . .	4.341	0.00238
Cadmium . . .	10.023	0.004190	"    -copper . .	2.904	0.00381
Lead . . . . .	20.970	0.005110	"    -bronze . .	13.906	0.0010
Thallium . . .	17.830	0.003980	Resistor . . . . .	76.466	0.0010
Mercury . . .	84.070	0.000780	Brass . . . . .	7.2	0.0010
Bismuth . . .	119.190	0.00480	Nickel . . . . .	88.50	—
Cobalt . . . .	9.71	0.00380	Carbon . . . . .	67000	—
Tantalum . .	14.6	0.00380	"    are light carb .	7000	0.0003
Tungsten . . .	9.0	0.0051	"    glow lamp Ed- swan . . . . .	4800	0.00054
Osmium . . . .	9.0	—	Phosphor bronze . .	—	—
			(commercial) . .	84.79	0.00064
			Constatan . . . .	47.48	0.000015
			Constantan . . . .	—	0.00001 to 0.00001
			Nickel Chroma . .	100	0.00043

\* A; practically pure.

\* Not determined by Fleming and Dewar.

TABLE XXI.

APPROXIMATE SPECIFIC RESISTANCE OF THE COMMONER LIQUIDS, AND WHICH DIMINISHES WITH INCREASE OF TEMPERATURE ABOUT 1.5% PER 1° C.

Solution.	Specific Resistance (Legal ohms per c.c.).	At a temperature (Degrees Cent.).
Sulphuric acid, 5% acid, sp. gr. 1.033	4.82	15
" " 10% " " 1.050	2.84	"
" " 20% " " 1.064	1.64	"
" " 25% " " 1.170	0.99	"
" " 30% " " 1.220	1.54	"
" " 40% " " 1.310	1.44	"
Common salt (ordinary)—saturated solution	5.10	"
Zinc sulphate " " "	20.3	"
Copper " " "	32.0	"
Salammoniac solution, sp. gr. 1.07	5.56	11
Water	$0.5 \times 10^6$	11
"	$100 \times 10^6$	70

TABLE XXII.

COMPARATIVE DATA FOR H.C. COPPER AND ALUMINIUM.

	Copper.	Aluminium.
Conductivity (Electrical) . . . . .	100	61.5
Tensile Strength (unannealed) . . . . .	25-30 tons	12-15 tons
Melting-Point . . . . .	1350° C.	700° C.
Specific Gravity . . . . .	8.9	2.7
Rectifical Area for Equal Conductivity . . . . .	1	1.56
Diameter " " " . . . . .	1	1.33
Weight " " " . . . . .	1	0.495
Temperature Co-efficient per 1° C. . . . .	0.0038	0.0052

TABLE XXIII.

## Eureka Resistance Material

A CUPRO-NICKEL ALLOY (SUPPLIED BY THE LONDON ELECTRIC WIRE CO. AND SMITH'S LTD.), PREPARED WITH GREAT CARE TO SECURE A NON-CORRODIBLE AND STABLE ALLOY.

Temperature Co-efficient . . . . .	0.00022 per deg. C.
Specific Resistance . . . . .	48 Microhms per cm. cuba.
Gravity . . . . .	8.8
Melting-Point . . . . .	1250° C.
Comparative Resistance . . . . .	29 times copper.
Tensile Strength . . . . .	40 tons per sq. inch.
Weight per cubic inch . . . . .	0.31 lb.

Resistance and carrying capacity for "open spirals" of Eureka wire in air, well ventilated with free radiation.

Gauge S.W.G.	Diameter.		Approx. Ampe giving temperature of			Resistance in Standard Ohms per 1000 yds. at 60° F. (20° C.)
	Inches.	mm.	100° C.	200° C.	300° C.	
6	.132	3.37				23.3
7	.112	2.87				27.7
8	.100	2.54	23.0	33	43.5	29.6
9	.084	2.15	26.0	43	50	41.3
10	.072	1.83	28.8	48	61.5	52.3
11	.063	1.60	31.0	50	65.5	63.7
12	.054	1.37	33.0	54	70.5	79.3
13	.048	1.22	35.7	58	76.5	101.3
14	.040	1.02	38.5	63	83.5	123.3
15	.035	.89	41.0	68	90.5	163.3
16	.030	.76	43.5	74	98.5	203.3
17	.026	.66	46.0	80	107.5	273.3
18	.022	.56	48.5	87	117.5	373.3
19	.019	.48	51.0	94	128.5	503.3
20	.017	.43	53.5	101	140.5	663.3
21	.015	.38	56.0	108	153.5	853.3
22	.013	.33	58.5	116	167.5	1093
23	.011	.28	61.0	124	182.5	1447
24	.010	.25	63.5	132	198.5	1777
25	.009	.23	66.0	140	215.5	2143
26	.008	.20	68.5	148	233.5	2643
27	.007	.18	71.0	156	252.5	3183
28	.006	.16	73.5	164	272.5	3863
29	.005	.13	76.0	172	293.5	4693
30	.004	.11	78.5	180	315.5	5683
31	.003	.09	81.0	188	338.5	6843
32	.002	.08	83.5	196	362.5	8183
33	.001	.07	86.0	204	387.5	9713
34	.001	.06	88.5	212	413.5	11443
35	.001	.05	91.0	220	440.5	13383
36	.001	.04	93.5	228	468.5	15543
37	.001	.03	96.0	236	497.5	17933
38	.001	.02	98.5	244	527.5	20563
39	.001	.02	101.0	252	558.5	23443
40	.001	.02	103.5	260	590.5	26583
41	.001	.02	106.0	268	623.5	30003
42	.001	.02	108.5	276	657.5	33723
43	.001	.02	111.0	284	692.5	37763
44	.001	.02	113.5	292	728.5	42143
45	.001	.02	116.0	300	765.5	46883
46	.001	.02	118.5	308	803.5	51993
47	.001	.02	121.0	316	842.5	57483

TABLE XXIV.

## Nickel Chrome Resistance Material

A HIGH RESISTANCE ALLOY (SUPPLIED BY THE LONDON ELECTRIC  
WIRE CO. AND SMITH'S LTD.).

Temperature Coefficient . . .	0.0048 per deg. C.
Specific Resistance . . . .	160 Microhms per cm. cube.
Gravity . . . . .	8.15.
Melting-Point . . . . .	1550° C.
Compressive Resistance . . .	58 times copper.
Tensile Strength . . . . .	47.12 tons per sq. inch.
Weight per cubic inch . . .	79 lb.

*Resistance and carrying capacity of Nickel Chrome Wire.*

Size A.W.G.	Approximate Resistance in Standard Ohms per 1000 yds. at temperature of			Approximate Amperes giving temperatures of		
	200° C.	400° C.	600° C.	200° C.	400° C.	600° C.
18	452	464	538	7.1	12	18
17	591	604	708	8.0	14	24
16	802	818	967	4.8	7.7	11
15	1154	1206	1378	3.7	5.7	8.4
14	1639	1690	1960	2.3	4.7	6.3
13	2200	2264	2660	1.7	4.2	5.1
12	2900	2983	3500	1.2	3.6	4.1
11	3917	4033	4780	1.0	3.4	3.8
10	5238	5387	6360	0.8	3.1	3.1
9	7030	7204	8570	0.6	2.9	3.0
8	9390	9685	11400	0.5	2.3	2.4
7	12640	13050	15500	0.4	1.9	2.0
6	16900	17430	20700	0.3	1.6	1.7
5	22800	23460	28000	0.2	1.3	1.4
4	30800	31600	37800	0.1	1.0	1.1
3	41400	42500	50800	0.1	0.8	0.9
2	55400	56800	67800	0.1	0.7	0.8
1	74400	76100	91800	0.1	0.6	0.7
0	100000	102000	122000	0.1	0.5	0.6



TABLE XXV.

THE FOLLOWING TABLE SHOWS THE CURRENT THAT WILL GIVE CERTAIN RISES IN TEMPERATURE IN VARIOUS GAUGES OF REOSTER'S RESISTANCE MATERIAL, AND ALSO THE RESISTANCES AND WATTS ABSORBED PER YARD IN EACH CASE (W. T. GLOVER AND CO.).

R. W. C.	Ohms per yard at 15° C.	50° C. rise in temperature.			100° C. rise in temperature.			150° C. rise in temperature.			200° C. rise in temperature.		
		Ohms per yard at 63.5° C.	Amps. giving a rise of 50° C.	Watts consumed per yard.	Ohms per yard at 113.5° C.	Amps. giving a rise of 100° C.	Watts consumed per yard.	Ohms per yard at 163.5° C.	Amps. giving a rise of 150° C.	Watts consumed per yard.	Ohms per yard at 213.5° C.	Amps. giving a rise of 200° C.	Watts consumed per yard.
8	0641	0371	20.1	23.1	0601	22.0	26.5	0481	29	96	0601	28	163
9	0652	0709	17.6	22.4	0743	22.1	26.0	0780	24	90	0817	23	151
10	0665	0809	15.1	20.3	0828	22.6	25.75	0884	27.8	79.00	108	23.6	131
11	1024	1060	12.2	18.3	1187	12.6	23.70	119	23.7	65.7	126	20.5	116
12	1200	126	11.9	17.4	143	12.6	22.85	150	20.3	61.2	157	20.0	106
13	1646	174	9.4	15.4	188	12.7	24.25	192	16.6	59.8	201	17.7	85
14	2180	220	7.6	13.2	242	11.6	22.55	254	12.9	49.0	266	12.0	66
15	2670	263	6.7	12.7	280	10.9	22.60	311	12.1	46.5	336	10.0	53
16	3383	357	5.7	11.6	377	8.60	27.90	384	10.6	43.4	413	12.4	74
17	4400	435	4.7	10.3	480	7.90	25.4	513	8.6	20.7	547	11.3	70
18	5606	534	4.0	10.15	607	5.82	23.5	700	7.85	37.8	788	9.27	63
19	6977	616	3.3	9.35	933	4.80	21.2	101	5.31	36.8	106	7.45	59
20	1009	113	2.64	9.12	113	4.22	21.5	124	4.25	34.2	120	6.50	56
21	12228	143	2.5	9.04	150	3.75	21.1	159	4.01	28.5	153	6.00	50
22	17686	186	2.15	8.05	156	3.20	21.4	208	4.03	28.5	216	4.27	55.5
23	24050	254	1.68	8.50	267	2.20	20.0	290	3.44	32.2	293	4.33	65.0
24	32658	302	1.02	7.03	318	2.55	20.4	384	3.12	32.5	350	3.00	54.4
25	34665	308	1.49	6.13	335	2.22	20.3	404	2.82	32.2	423	2.67	54.0
26	42764	451	1.29	7.65	475	2.05	20.0	468	2.53	31.6	522	2.19	62.7
27	51331	544	1.2	7.83	573	1.84	19.4	600	2.26	31.4	629	2.00	62.2
28	63279	568	1.07	7.68	702	1.55	18.1	727	2.05	31.0	778	2.20	62.3
29	74928	791	.98	7.69	832	1.91	18.0	873	1.87	30.4	914	2.25	60.8
30	901136	901	.805	7.61	10.00	1.66	18.5	1050	1.69	29.9	1100	2.10	50.8

TABLE XXVI.

RELATION BETWEEN GAUGES OF COVERED MANGANIN WIRE AND CURRENTS  
GIVING A RISE OF TEMPERATURE OF 100° C. ABOVE THE OUTSIDE  
AIR (W. T. GLOVER AND CO.).

No. B.W.G.	Ampere.	No. B.W.G.	Ampere.	No. B.W.G.	Ampere.	No. B.W.G.	Ampere.
2	20.8	12	12.0	22	1.67	32	0.080
3	19.0	13	9.8	23	1.22	33	0.035
4	16.0	14	7.07	24	1.028	34	0.01
5	14.0	15	6.47	25	0.922	35	0.272
6	12.0	16	5.65	26	0.807	36	0.255
7	10.5	17	4.68	27	0.677	37	0.209
8	9.25	18	3.63	28	0.545	38	0.155
9	7.90	19	2.90	29	0.467	39	0.157
10	6.4	20	2.2	30	0.410	40	0.140
11	5.0	21	1.9	31	0.410		

NOTE.—For bare wires in air Mr. L. R. Atkinson allows 1 sq. in. of total external surface per Watt to be dissipated for a temperature of 150° C.

TABLE XXVII.

SHOWING THE CURRENTS THAT WILL PRODUCE 212° F. (100° C.) RISE IN  
TEMPERATURE ABOVE THE SURROUNDING AIR FOR BARE MANGANIN  
WIRE STRETCHED HORIZONTALLY AND FREELY EXPOSED TO THE AIR  
(W. T. GLOVER AND CO.).

B.W.G. . . .	No.	8	9	10	11	12	13	14
Ampere. . .		80	50	40	33	30	25	20
B.W.G. . . .	No.	12	13	14	15	16	17	18
Ampere. . .		15	13	10	9	8	6	5

NOTE.—If placed vertically or coiled, an allowance must be made.

TABLE XXVIII.

DENSITIES OF DRY AIR IN LBS. PER CUBIC FOOT AT DIFFERENT TEMPERATURES AND PRESSURES CALCULATED BY THE RELATION (LBS. PER CUBIC FOOT) =  $\left\{ \frac{0.001293}{1 + 0.00367 \times T} \times \frac{H}{760} \right\} \times 62.43$ , WHERE T = TEMP. IN °C. AND H = PRESSURE IN MM. OF MERCURY AT 0° C., LAT. 45°,  $g = 980.62$ . 0.001293 = DENSITY IN GRAMS PER C.C. AT 0° C. AND 760 MM. PRESSURE OF MERCURY. 1 GRAM PER C.C. = 62.43 LBS. PER CUBIC FOOT.

Temp. ° C.	Barometric Pressure in Millimeters of Mercury = H.							
	710 mm. 27.95 in.	720 28.34	730 28.74	740 29.13	750 29.52	760 29.92	770 30.31	780 30.70
0	0.07341	0.07547	0.07754	0.07959	0.08166	0.08372	0.08579	0.08785
5	7400	7506	7617	7718	7821	7923	8030	8134
10	7274	7381	7490	7578	7685	7784	7893	7991
15	7148	7246	7348	7447	7554	7647	7754	7847
20	7039	7134	7235	7328	7425	7521	7617	7710
25	6934	7026	7125	7217	7309	7401	7493	7584
30	6791	6885	6984	7079	7173	7274	7367	7461

TABLE XXIX.

COMPARISON OF WIRE GAUGES IN COMMON USE.

No.	S.W.G. Inch.	R.W.G. Inch.	B. & S. Inch.	No.	S.W.G. Inch.	R.W.G. Inch.	B. & S. Inch.	No.	S.W.G. Inch.	R.W.G. Inch.	B. & S. Inch.
4/0	.400	.454	.4000	15	.072	.079	.0771	35	.0100	.008	.0071
3/0	.372	.425	.3706	16	.064	.065	.0606	36	.0092	.007	.0063
2/0	.346	.380	.3348	17	.058	.058	.0485	37	.0084	.006	.0054
0	.324	.345	.3249	18	.048	.049	.0408	38	.0076	.004	.0050
1	.300	.300	.2983	19	.040	.043	.0359	39	.0068		.0046
2	.276	.281	.2775	20	.036	.035	.0320	40	.0060		.0040
3	.259	.260	.2564	21	.032	.032	.0285	41	.0054		.0035
4	.243	.239	.2348	22	.028	.028	.0265	42	.0048		.0031
5	.218	.220	.2191	23	.024	.025	.0230	43	.0044		
6	.192	.190	.1920	24	.021	.023	.0201	44	.0040		
7	.178	.180	.1744	25	.018	.020	.0171	45	.0036		
8	.165	.163	.1588	26	.016	.018	.0160	46	.0032		
9	.144	.144	.1444	27	.014	.016	.0142	47	.0028		
10	.128	.124	.1219	28	.012	.014	.0120	48	.0024		
11	.112	.120	.0907	29	.010	.012	.0112	49	.0020		
12	.104	.106	.0804	30	.009	.011	.0100	50	.0016		
13	.092	.095	.0739	31	.008	.010	.0080	51	.0014		
14	.089	.088	.0641	32	.008	.009	.0070	52	.0010		

## Photometer Bench.

TABLE XXX.

RATIOS OF SQUARES OF DISTANCES FROM SCREEN TO SOURCES OF LIGHT FOR DIFFERENT DISTANCES ( $D$ ) BETWEEN THE LATTER (FOR FACILITATING CALCULATIONS OF CANDLE POWERS).

C.P. to be determined = C.P. of standard  $\times \frac{(D - d)^2}{d^2}$  where ( $d$ ) = distance between screen and standard.

Note.—Intermediate values may very approximately be found by proportion, but should be obtained from a curve between  $d$  and  $\frac{(D - d)^2}{d^2}$  when required more accurately.

$(D - d)^2$	$D =$					$(D - d)^2$	$D =$				
	200	300	400	500	600		200	300	400	500	600
$d^2$	$d$	$d$	$d$	$d$	$d$	$d^2$	$d$	$d$	$d$	$d$	$d$
81.00	9.0	10.0	11.0	12.0	13.0	17.64	4.2	4.5	4.8	5.1	5.4
73.44	8.6	9.5	10.5	11.5	12.5	16.00	4.0	4.3	4.6	4.9	5.2
65.76	8.1	8.8	9.6	10.4	11.2	14.44	3.8	4.1	4.4	4.7	5.0
57.96	7.6	8.3	9.0	9.7	10.4	12.96	3.6	3.9	4.2	4.5	4.8
50.04	7.1	7.7	8.3	8.9	9.5	11.56	3.4	3.7	4.0	4.3	4.6
42.00	6.5	7.0	7.5	8.0	8.5	10.24	3.2	3.5	3.8	4.1	4.4
33.84	5.8	6.2	6.6	7.0	7.4	8.84	2.9	3.2	3.5	3.8	4.1
25.56	5.1	5.4	5.7	6.0	6.3	7.44	2.7	2.9	3.2	3.5	3.8
17.16	4.2	4.4	4.6	4.8	5.0	6.04	2.5	2.7	2.9	3.1	3.3
8.64	3.1	3.2	3.3	3.4	3.5	4.64	2.1	2.2	2.3	2.4	2.5
						3.24	1.8	1.9	2.0	2.1	2.2
						1.96	1.4	1.5	1.6	1.7	1.8
						1.69	1.3	1.4	1.5	1.6	1.7
						1.44	1.2	1.3	1.4	1.5	1.6
						1.21	1.1	1.2	1.3	1.4	1.5
						1.00	1.0	1.1	1.2	1.3	1.4
						0.81	0.9	1.0	1.1	1.2	1.3
						0.64	0.8	0.9	1.0	1.1	1.2
						0.49	0.7	0.8	0.9	1.0	1.1
						0.36	0.6	0.7	0.8	0.9	1.0
						0.25	0.5	0.6	0.7	0.8	0.9
						0.16	0.4	0.5	0.6	0.7	0.8
						0.09	0.3	0.4	0.5	0.6	0.7
						0.04	0.2	0.3	0.4	0.5	0.6
						0.01	0.1	0.2	0.3	0.4	0.5

(R - d) d	D =					(R - d) d	D =				
	200	300	400	500	600		200	300	400	500	600
d	d	d	d	d	d	d	d	d	d	d	d
4 123	80.0	90.0	125	160.0	196.0	0.0678	133.5	230.25	307	383.75	460.0
8 941	7	160.5	4	7.5	201	0.0692	4.0	1.0	8	6.0	2.0
8 769	8	2.0	6	170.0	4	0.0687	4.2	1.75	9	8.25	2.5
8 904	9	2.5	8	2.5	1	0.0682	6.0	2.5	10	7.5	3.0
8 45	10.0	3.0	14.0	6.0	510	0.0610	8.5	3.55	1	8.75	4.5
8 691	11.5	3.75	13.5	181.25	7.5	0.0735	6.0	4.0	2	30.0	8.0
2 777	12.0	112.5	150	7.8	225.0	0.0778	6.5	4.75	2	1.25	0.5
2 600	13.5	6.25	155	180.75	225.5	0.0751	7.0	5.5	4	2.5	0.71.0
2 25	14.0	120.0	160	250.0	240.0	0.0738	7.5	6.25	6	3.75	1.5
2 025	15.5	8.75	165	300.25	1.5	0.0727	8.0	7.0	6	5.0	4.0
1 831	16.0	7.5	170	212.5	255.0	0.0696	8.5	7.75	7	6.25	5.5
1 654	17.5	131.25	175	218.75	262.5	0.0665	9.0	8.5	8	7.5	7.0
1 49	18.0	6.0	180	225.0	270.0	0.0645	9.5	9.25	9	8.75	8.5
1 300	19.5	8.75	185	231.25	7.5	0.0625	100.0	240.0	330	400.0	450.0
1 222	20.0	142.5	190	237.5	285.0	0.0606	0.5	0.75	1	1.50	1.5
1 126	21.5	0.25	195	243.75	292.5	0.0587	1.0	1.5	2	2.5	2.0
1	22.0	150.0	200	250.0	300.0	0.0568	1.5	2.25	3	3.75	3.5
0 9045	23.5	2.75	205	256.25	7.5	0.0551	2.0	3.0	4	5.0	4.0
0 8182	24.0	7.5	210	262.5	312.0	0.0535	2.5	3.75	5	6.25	7.5
0 7407	25.5	161.50	215	268.75	319.5	0.0519	3.0	4.5	6	7.5	8.0
0 6711	26.0	5.0	220	275.0	326.0	0.0500	3.5	5.25	7	8.75	400.5
0 6046	27.5	8.75	225	281.25	7.5	0.0483	4.0	6.0	8	410.0	3.0
0 5461	28.0	172.5	230	287.5	246.0	0.0466	4.5	6.75	9	1.25	8.5
0 4929	29.5	0.25	235	293.75	252.5	0.0450	5.0	7.5	10	2.5	8.0
0 44	30.0	180.0	240	300.0	259.0	0.0435	5.5	8.25	1	3.75	8.5
0 400	31.5	2.75	245	306.25	7.5	0.0419	6.0	9.0	2	5.0	8.0
0 3601	32.0	7.5	250	312.5	275.0	0.0405	6.5	9.75	3	6.25	9.5
0 3236	33.5	191.25	255	318.75	281.5	0.0391	7.0	10.5	4	7.5	101.0
0 29	34.0	5.0	260	325.0	300.0	0.0377	7.5	11.25	5	8.75	3.5
0 2778	35.5	0.5	2	7.5	3	0.0363	8.0	12.0	6	420.0	4.0
0 2555	36.0	8.0	4	570.0	6	0.0349	8.5	12.75	7	1.25	1.5
0 2357	37.5	9.5	5	2.5	0	0.0335	9.0	13.5	8	2.5	7.0
0 2125	38.0	101.0	6	5.0	402	0.0322	9.5	14.25	9	3.75	8.5
0 2318	39.5	2.5	270	7.5	3	0.0311	170.0	255.0	340	5.0	510.0
0 2117	40.0	4.0	2	340.0	3	0.0299	0.5	6.75	1	6.55	1.5
0 2114	41.5	5.5	4	2.5	411	0.0288	1.0	7.5	2	7.5	2.0
0 2037	42.0	7.0	5	5.0	4	0.0276	1.5	7.25	3	8.75	4.0
0 1958	43.5	8.5	6	7.5	7	0.0265	2.0	8.0	4	450.0	4.0
0 1889	140.0	510.0	280	330.0	430	0.0254	2.5	8.75	5	1.25	7.5
0 1791	1	1.5	2	2.5	8	0.0244	3.0	9.5	6	2.5	9.0
0 1679	2	3.0	4	5.0	8	0.0233	3.5	10.25	7	3.75	690.5
0 159	3	4.5	6	7.5	9	0.0223	4.0	11.0	8	5.0	3.0
0 1512	4	6.0	8	100.0	432	0.0214	4.5	11.75	9	6.25	3.5
0 1430	5	7.5	10	2.0	3	0.0204	5.0	12.5	10	7.5	5.0
0 1370	6	9.0	12	5.0	8	0.0195	5.5	13.25	1	8.75	8.5
0 1300	7	10.5	14	7.5	441	0.0185	6.0	14.0	2	410.0	8.0
0 1255	8	12.0	16	10.0	4	0.0177	6.5	14.75	3	1.25	9.5
0 1172	9	13.5	18	12.5	7	0.0169	7.0	15.5	4	2.5	601.0
0 1112	10.0	15.0	20	15.0	450	0.0161	7.5	16.25	5	3.75	2.5
0 1061	0.5	5.75	1	8.25	1.5	0.0153	8.0	17.0	6	5.0	4.0
0 1008	1.0	6.5	2	7.5	3.0	0.0145	8.5	17.75	7	6.25	5.5
0 955	1.5	7.25	3	8.75	4.5	0.0139	9.0	18.5	8	7.5	7.0
0 902	2.0	8.0	4	100.0	6.0	0.0133	9.5	19.25	9	8.75	8.5
0 8571	2.5	8.75	5	1.25	7.5	0.0124	100.0	215.0	300	450.0	640.0
0 804	3.0	9.5	6	2.5	9.0						

TABLE XXXI.

TABLE OF STEEL, WIRE, AND RESISTANCE FOR SOME IMPORTANT HIGH RESISTANCE MATERIALS AT 60° F.

Size.	No. of wires.	Area, sq. in.	Tens. to the lb.		Copper.		Human Silver.		Platinoid.		Eureka.		Mangan.		Resist.	
			Governed (approx.)	Resistance (approx.)	Resistance (approx.)	Resistance (approx.)	Resistance bars (approx.)	Resistance bars (approx.)	Resistance bars (approx.)	Resistance bars (approx.)	Resistance.	Resistance.	Resistance.	Resistance.	per 1000 yds.	per lb.
No.	Size.	Area.	3011	3012	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3013	3014	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3015	3016	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3017	3018	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3019	3020	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3021	3022	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3023	3024	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3025	3026	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3027	3028	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3029	3030	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3031	3032	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3033	3034	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3035	3036	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3037	3038	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3039	3040	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3041	3042	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3043	3044	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3045	3046	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3047	3048	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3049	3050	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3051	3052	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3053	3054	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3055	3056	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3057	3058	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3059	3060	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3061	3062	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3063	3064	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3065	3066	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3067	3068	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3069	3070	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3071	3072	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3073	3074	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3075	3076	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3077	3078	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3079	3080	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3081	3082	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3083	3084	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3085	3086	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3087	3088	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3089	3090	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3091	3092	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3093	3094	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3095	3096	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.
			concl.	concl.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.	ohms.
No.	Size.	Area.	3097	3098	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per 1000	per lb.	per			

TABLE XXXII.

THE TABLE GIVEN BELOW SHOWS THE SIZES OF VARIOUS WIRES OF DIFFERENT MATERIALS WHICH WILL FUSE AT THE CURRENTS GIVEN IN THE FIRST COLUMN (SEE W. H. PRETOR).

Currents in Amperes.	Tin Wire.		Lead Wire.		Copper Wire.		Iron Wire.	
	Diameter Inches.	Approx. S.W.G.	Diameter Inches.	Approx. S.W.G.	Diameter Inches.	Approx. S.W.G.	Diameter Inches.	Approx. S.W.G.
1	0.0072	36	0.0061	35	0.0071	47	0.0067	45
2	0.0115	31	0.0122	30	0.0084	42	0.0074	40
3	0.0140	28	0.0138	27	0.0094	41	0.0077	38
4	0.0181	26	0.0205	25	0.0093	39	0.0117	31
5	0.0210	25	0.0236	24	0.0092	38	0.0126	29
10	0.0284	21	0.0375	20	0.0098	36	0.0216	24
15	0.0487	18	0.0491	18	0.0123	30	0.0223	21
20	0.0529	17	0.0556	17	0.0156	28	0.0248	20.5
25	0.0616	16	0.0620	15	0.0181	26	0.0268	19
30	0.0684	15	0.0779	14	0.0205	25	0.0480	18.5
36	0.0709	14.5	0.0864	13.5	0.0227	24	0.0498	18
40	0.0840	13.5	0.0944	13	0.0245	23	0.0545	17
45	0.0909	13	0.1021	12	0.0269	22	0.0589	16.5
50	0.0975	12.5	0.1025	11.5	0.0288	21	0.0622	16
60	0.1161	11	0.1237	10	0.0325	21	0.0714	15
70	0.1220	10	0.1371	9.5	0.0360	20	0.0791	14
80	0.1364	9.5	0.1499	9.5	0.0394	19	0.0864	13.5
90	0.1449	9	0.1621	9	0.0436	18.5	0.0965	13
100	0.1549	8.5	0.1769	7	0.0467	18	0.1068	12
120	0.1748	7	0.1964	6	0.0510	17.5	0.1182	11
140	0.1937	6	0.2176	6	0.0571	17	0.1255	10
160	0.2118	5	0.2379	4	0.0625	16	0.1371	9.5
180	0.2291	4	0.2573	4	0.0678	16	0.1484	9
200	0.2457	3.5	0.2765	3	0.0725	15	0.1592	8
250	0.2861	1.5	0.3305	0	0.0841	13.5	0.1848	7.5

Note.—The above numbers can only be taken as approximate, as the actual current required to fuse any gauge will depend on the length of fuse and cooling effects of the fuse block in which it is placed.

In All- tin diameters 2% greater than those of lead fuse at the same currents.

### Useful Numbers.

Metres	×	3.2809	= feet.
Feet	×	0.3048	= metres.
Centimetres	×	0.3937	= inches.
Inches	×	2.54	= cms.
Mils.	×	0.0254	= millimetres.
Sq. cms.	×	0.155	= sq. inches.
Sq. inches	×	0.00155	= sq. mm.
Sq. inches	×	6.451	= sq. cms.
Cubic "	×	16.387	= cub. "
" cms.	×	0.061027	= " inches.

Kilogrammes	×	2.2046	= pounds.
Miles	×	1.609	= kilometres.
Kilometres	×	1094	= yards.
Pounds (avoir.)	×	0.4536	= kilogrammes.
Gallons		0.1604	= cubic ft.
Cubic ft.		6.2355	= gallons.
Gallons (water)	×	10.0	= pounds.
Cub. ft. ( " )	×	62.27	= " "
Metres	×	39.3704	= inches.
Foot	×	30.4797	= cms.
Pounds (avoir.)	×	453.593	= grammes.
Revs. per sec.	×	6.2832	= radians per sec.
Feet " min.	×	0.005	= metres per " "
Metres " sec.	×	197	= ft. per min.
Joules Equivalent	=	1390 lb. cent. units	
	=	$4.156 \times 10^7$	ergs per gram. °C.
Acceleration due to Gravity ( $g$ ) at Greenwich		= 32.1908	ft. sec. units
		= 981.17	cm. " "
Density of mercury	=	13.596	grammes per c.c.
Watts	×	0.7373	= foot lbs. per sec.
Joules (i. e. Watt secs.)	×	$10^7$	= ergs.
" "	×	0.7373	= ft. lbs.
" "	×	0.239	= calories.
Calories	×	4.158	= Joules.
Ft. lbs.	×	1.35	= " "
Kilogrammetres	×	7.233	= ft. lbs.
Ft. lbs.	×	0.138	= kilogrammetres.
Horse-power	×	746	= Watts.
" "	×	33000	= ft. lbs. per min.
" "	×	550	= " " sec.
" "	×	70	= kilogrammetres per sec.
Watts	×	44.25	= ft. lbs. per min.
" "	×	0.1	= kilogrammetres per sec.
H.P. hours	×	1980000	= ft. lbs.
" "	×	2685600	= Joules.
Kilowatt hours	×	1.34	= H.P. hours.
" " "	×	2656400	= ft. lbs.
Length of circumference of circle radius ( $r$ ) = $2\pi r = \pi d$ .			



Area of circumference of circle radius ( $r$ ) =  $\pi r^2 = \frac{\pi d^2}{4} = .7854d^2$ .

Ratio of circumference of circle to its diam. " .

( $\pi$ ) = 3.14159 =  $\frac{22}{7}$  approx.

$\log. \pi = 0.4971499$ .

Base of hyperbolic or Napierian logarithms  $e = 2.71828$  . . .

To convert *Napierian into Common logarithms* multiply by 0.43429.

To convert *Common into Napierian logarithms* multiply by 2.30258.

Lbs. per yard of pure copper wire = area in sq. ins.  $\times 11.5625$ .

Ohms per yard of pure copper wire at 60° F. (15.5°C.)

=  $0.0000244657 \div$  area in sq. ins.

Pounds per 1000 yards  $\div 10\%$  = pounds per kilometre.

" " 1000 "  $\div 2$  = kilograms per "

## LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0129	0171	0212	0253	0294	0334	0374	4	5	6	7	8	9	10	11	12
11	0414	0455	0496	0536	0576	0615	0654	0692	0730	0768	13	14	15	16	17	18	19	20	21
12	0799	0838	0876	0914	0951	0988	1024	1060	1096	1131	22	23	24	25	26	27	28	29	30
13	1159	1195	1230	1265	1300	1334	1368	1401	1435	1468	31	32	33	34	35	36	37	38	39
14	1497	1530	1562	1594	1626	1657	1688	1719	1750	1780	40	41	42	43	44	45	46	47	48
15	1791	1821	1851	1881	1911	1940	1969	1998	2026	2054	49	50	51	52	53	54	55	56	57
16	2083	2110	2137	2164	2190	2216	2242	2267	2292	2317	58	59	60	61	62	63	64	65	66
17	2342	2367	2391	2415	2439	2463	2486	2509	2532	2555	67	68	69	70	71	72	73	74	75
18	2578	2601	2624	2646	2668	2690	2712	2733	2754	2775	76	77	78	79	80	81	82	83	84
19	2795	2816	2837	2857	2877	2897	2917	2936	2955	2974	85	86	87	88	89	90	91	92	93
20	2993	3012	3031	3050	3068	3087	3105	3124	3142	3160	94	95	96	97	98	99	100	101	102
21	3178	3196	3214	3232	3250	3267	3284	3301	3318	3335	103	104	105	106	107	108	109	110	111
22	3352	3368	3384	3400	3416	3432	3447	3463	3478	3493	112	113	114	115	116	117	118	119	120
23	3508	3523	3538	3553	3568	3582	3597	3611	3626	3640	121	122	123	124	125	126	127	128	129
24	3654	3668	3682	3696	3710	3724	3737	3751	3764	3777	130	131	132	133	134	135	136	137	138
25	3791	3804	3817	3830	3843	3855	3868	3880	3892	3904	139	140	141	142	143	144	145	146	147
26	3916	3928	3940	3952	3963	3974	3985	3996	4007	4018	148	149	150	151	152	153	154	155	156
27	4029	4040	4051	4061	4071	4081	4091	4101	4111	4121	157	158	159	160	161	162	163	164	165
28	4131	4141	4151	4161	4171	4181	4191	4201	4211	4221	166	167	168	169	170	171	172	173	174
29	4231	4241	4251	4261	4271	4281	4291	4301	4311	4321	175	176	177	178	179	180	181	182	183
30	4331	4341	4351	4361	4371	4381	4391	4401	4411	4421	184	185	186	187	188	189	190	191	192
31	4431	4441	4451	4461	4471	4481	4491	4501	4511	4521	193	194	195	196	197	198	199	200	201
32	4531	4541	4551	4561	4571	4581	4591	4601	4611	4621	202	203	204	205	206	207	208	209	210
33	4631	4641	4651	4661	4671	4681	4691	4701	4711	4721	211	212	213	214	215	216	217	218	219
34	4731	4741	4751	4761	4771	4781	4791	4801	4811	4821	220	221	222	223	224	225	226	227	228
35	4831	4841	4851	4861	4871	4881	4891	4901	4911	4921	229	230	231	232	233	234	235	236	237
36	4931	4941	4951	4961	4971	4981	4991	5001	5011	5021	238	239	240	241	242	243	244	245	246
37	5031	5041	5051	5061	5071	5081	5091	5101	5111	5121	247	248	249	250	251	252	253	254	255
38	5131	5141	5151	5161	5171	5181	5191	5201	5211	5221	256	257	258	259	260	261	262	263	264
39	5231	5241	5251	5261	5271	5281	5291	5301	5311	5321	265	266	267	268	269	270	271	272	273
40	5331	5341	5351	5361	5371	5381	5391	5401	5411	5421	274	275	276	277	278	279	280	281	282
41	5431	5441	5451	5461	5471	5481	5491	5501	5511	5521	283	284	285	286	287	288	289	290	291
42	5531	5541	5551	5561	5571	5581	5591	5601	5611	5621	292	293	294	295	296	297	298	299	300
43	5631	5641	5651	5661	5671	5681	5691	5701	5711	5721	301	302	303	304	305	306	307	308	309
44	5731	5741	5751	5761	5771	5781	5791	5801	5811	5821	310	311	312	313	314	315	316	317	318
45	5831	5841	5851	5861	5871	5881	5891	5901	5911	5921	319	320	321	322	323	324	325	326	327
46	5931	5941	5951	5961	5971	5981	5991	6001	6011	6021	328	329	330	331	332	333	334	335	336
47	6031	6041	6051	6061	6071	6081	6091	6101	6111	6121	337	338	339	340	341	342	343	344	345
48	6131	6141	6151	6161	6171	6181	6191	6201	6211	6221	346	347	348	349	350	351	352	353	354
49	6231	6241	6251	6261	6271	6281	6291	6301	6311	6321	355	356	357	358	359	360	361	362	363
50	6331	6341	6351	6361	6371	6381	6391	6401	6411	6421	364	365	366	367	368	369	370	371	372
51	6431	6441	6451	6461	6471	6481	6491	6501	6511	6521	373	374	375	376	377	378	379	380	381
52	6531	6541	6551	6561	6571	6581	6591	6601	6611	6621	382	383	384	385	386	387	388	389	390
53	6631	6641	6651	6661	6671	6681	6691	6701	6711	6721	391	392	393	394	395	396	397	398	399
54	6731	6741	6751	6761	6771	6781	6791	6801	6811	6821	400	401	402	403	404	405	406	407	408
55	6831	6841	6851	6861	6871	6881	6891	6901	6911	6921	409	410	411	412	413	414	415	416	417
56	6931	6941	6951	6961	6971	6981	6991	7001	7011	7021	418	419	420	421	422	423	424	425	426
57	7031	7041	7051	7061	7071	7081	7091	7101	7111	7121	427	428	429	430	431	432	433	434	435
58	7131	7141	7151	7161	7171	7181	7191	7201	7211	7221	436	437	438	439	440	441	442	443	444
59	7231	7241	7251	7261	7271	7281	7291	7301	7311	7321	445	446	447	448	449	450	451	452	453
60	7331	7341	7351	7361	7371	7381	7391	7401	7411	7421	454	455	456	457	458	459	460	461	462
61	7431	7441	7451	7461	7471	7481	7491	7501	7511	7521	463	464	465	466	467	468	469	470	471
62	7531	7541	7551	7561	7571	7581	7591	7601	7611	7621	472	473	474	475	476	477	478	479	480
63	7631	7641	7651	7661	7671	7681	7691	7701	7711	7721	481	482	483	484	485	486	487	488	489
64	7731	7741	7751	7761	7771	7781	7791	7801	7811	7821	490	491	492	493	494	495	496	497	498
65	7831	7841	7851	7861	7871	7881	7891	7901	7911	7921	499	500	501	502	503	504	505	506	507
66	7931	7941	7951	7961	7971	7981	7991	8001	8011	8021	508	509	510	511	512	513	514	515	516
67	8031	8041	8051	8061	8071	8081	8091	8101	8111	8121	517	518	519	520	521	522	523	524	525
68	8131	8141	8151	8161	8171	8181	8191	8201	8211	8221	526	527	528	529	530	531	532	533	534
69	8231	8241	8251	8261	8271	8281	8291	8301	8311	8321	535	536	537	538	539	540	541	542	543
70	8331	8341	8351	8361	8371	8381	8391	8401	8411	8421	544	545	546	547	548	549	550	551	552
71	8431	8441	8451	8461	8471	8481	8491	8501	8511	8521	553	554	555	556	557	558	559	560	561
72	8531	8541	8551	8561	8571	8581	8591	8601	8611	8621	562	563	564	565	566	567	568	569	570
73	8631	8641	8651	8661	8671	8681	8691	8701	8711	8721	571	572	573	574	575	576	577	578	579
74	8731	8741	8751	8761	8771	8781	8791	8801	8811	8821	580	581	582	583	584	585	586	587	588
75	8831	8841	8851	8861	8871	8881	8891	8901	8911	8921	589	590	591	592	593	594	595	596	597
76	8931	8941	8951	8961	8971	8981	8991	9001	9011	9021	598	599	600	601	602	603	604	605	606
77	9031	9041	9051	9061	9071	9081	9091	9101	9111	9121	607	608	609	610	611	612	613	614	615
78	9131	9141	9151	9161	9171	9181	9191	9201	9211	9221	616	617	618	619	620	621	622	623	624
79	9231	9241	9251	9261	9271	9281	9291	9301	9311	9321	625	626	627	628	629	630			

## LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
50	7404	7412	7416	7427	7435	7440	7451	7460	7466	7474	1	2	3	4	5	6	7			
51	7488	7490	7497	7503	7510	7519	7526	7536	7543	7551	1	2	3	4	5	6	7			
52	7560	7566	7574	7581	7589	7597	7604	7611	7619	7627	1	2	3	4	5	6	7			
53	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	2	3	4	5	6	7			
54	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	2	3	4	5	6	7			
55	7782	7790	7797	7805	7812	7819	7826	7833	7840	7846	1	2	3	4	5	6	7			
56	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	2	3	4	5	6	7			
57	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	2	3	4	5	6	7			
58	7995	8002	8007	8014	8021	8028	8035	8041	8048	8055	1	2	3	4	5	6	7			
59	8062	8069	8075	8082	8089	8096	8103	8109	8116	8123	1	2	3	4	5	6	7			
60	8129	8136	8143	8149	8156	8163	8170	8177	8183	8190	1	2	3	4	5	6	7			
61	8196	8203	8210	8216	8223	8229	8235	8241	8248	8254	1	2	3	4	5	6	7			
62	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	2	3	4	5	6	7			
63	8325	8331	8338	8344	8351	8357	8363	8370	8376	8383	1	2	3	4	5	6	7			
64	8389	8396	8402	8407	8414	8420	8426	8432	8439	8445	1	2	3	4	5	6	7			
65	8451	8457	8463	8470	8476	8483	8489	8494	8500	8506	1	2	3	4	5	6	7			
66	8512	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	2	3	4	5	6	7			
67	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	2	3	4	5	6	7			
68	8633	8639	8645	8651	8657	8663	8669	8675	8681	8687	1	2	3	4	5	6	7			
69	8693	8699	8704	8710	8716	8722	8727	8733	8739	8745	1	2	3	4	5	6	7			
70	8751	8756	8763	8769	8774	8779	8785	8791	8797	8803	1	2	3	4	5	6	7			
71	8808	8814	8820	8826	8831	8837	8842	8848	8854	8860	1	2	3	4	5	6	7			
72	8865	8871	8877	8883	8887	8893	8899	8904	8910	8915	1	2	3	4	5	6	7			
73	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	2	3	4	5	6	7			
74	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	2	3	4	5	6	7			
75	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	2	3	4	5	6	7			
76	9085	9090	9096	9101	9106	9112	9117	9123	9128	9133	1	2	3	4	5	6	7			
77	9138	9143	9148	9154	9159	9165	9170	9175	9180	9186	1	2	3	4	5	6	7			
78	9191	9196	9201	9207	9212	9217	9222	9227	9232	9238	1	2	3	4	5	6	7			
79	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	2	3	4	5	6	7			
80	9294	9299	9304	9309	9314	9319	9324	9329	9334	9339	1	2	3	4	5	6	7			
81	9344	9349	9354	9359	9364	9369	9374	9379	9384	9389	1	2	3	4	5	6	7			
82	9394	9399	9404	9409	9414	9419	9424	9429	9434	9439	1	2	3	4	5	6	7			
83	9444	9449	9454	9459	9464	9469	9474	9479	9484	9489	1	2	3	4	5	6	7			
84	9494	9499	9504	9509	9514	9519	9524	9529	9534	9539	1	2	3	4	5	6	7			
85	9544	9549	9554	9559	9564	9569	9574	9579	9584	9589	1	2	3	4	5	6	7			
86	9594	9599	9604	9609	9614	9619	9624	9629	9634	9639	1	2	3	4	5	6	7			
87	9644	9649	9654	9659	9664	9669	9674	9679	9684	9689	1	2	3	4	5	6	7			
88	9694	9699	9704	9709	9714	9719	9724	9729	9734	9739	1	2	3	4	5	6	7			
89	9744	9749	9754	9759	9764	9769	9774	9779	9784	9789	1	2	3	4	5	6	7			
90	9794	9799	9804	9809	9814	9819	9824	9829	9834	9839	1	2	3	4	5	6	7			
91	9844	9849	9854	9859	9864	9869	9874	9879	9884	9889	1	2	3	4	5	6	7			
92	9894	9899	9904	9909	9914	9919	9924	9929	9934	9939	1	2	3	4	5	6	7			
93	9944	9949	9954	9959	9964	9969	9974	9979	9984	9989	1	2	3	4	5	6	7			
94	9994	9999	10004	10009	10014	10019	10024	10029	10034	10039	1	2	3	4	5	6	7			

## ANTI-LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
90	1080	1029	1005	1007	1000	1019	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
91	1032	1026	1028	1020	1023	1025	1028	1040	1042	1045	0	0	3	1	1	1	2	2	2
92	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	2	1	1	1	2	2	2
93	1073	1074	1075	1077	1081	1084	1086	1089	1091	1093	0	0	2	1	1	1	2	2	2
94	1098	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
95	1122	1132	1137	1140	1142	1145	1148	1149	1152	1154	0	1	1	1	1	2	2	2	2
96	1158	1167	1169	1172	1175	1177	1180	1182	1184	1187	0	1	1	1	1	2	2	2	2
97	1174	1178	1180	1182	1184	1186	1188	1191	1194	1197	0	1	1	1	1	2	2	2	2
98	1200	1202	1204	1207	1210	1212	1214	1216	1219	1221	0	1	1	1	1	2	2	2	2
99	1223	1225	1228	1230	1232	1234	1236	1238	1240	1242	0	1	1	1	1	2	2	2	2
10	1244	1246	1248	1250	1252	1254	1256	1258	1260	1262	0	1	1	1	1	2	2	2	2
11	1264	1266	1268	1270	1272	1274	1276	1278	1280	1282	0	1	1	1	1	2	2	2	2
12	1284	1286	1288	1290	1292	1294	1296	1298	1300	1302	0	1	1	1	1	2	2	2	2
13	1304	1306	1308	1310	1312	1314	1316	1318	1320	1322	0	1	1	1	1	2	2	2	2
14	1324	1326	1328	1330	1332	1334	1336	1338	1340	1342	0	1	1	1	1	2	2	2	2
15	1344	1346	1348	1350	1352	1354	1356	1358	1360	1362	0	1	1	1	1	2	2	2	2
16	1364	1366	1368	1370	1372	1374	1376	1378	1380	1382	0	1	1	1	1	2	2	2	2
17	1384	1386	1388	1390	1392	1394	1396	1398	1400	1402	0	1	1	1	1	2	2	2	2
18	1404	1406	1408	1410	1412	1414	1416	1418	1420	1422	0	1	1	1	1	2	2	2	2
19	1424	1426	1428	1430	1432	1434	1436	1438	1440	1442	0	1	1	1	1	2	2	2	2
20	1444	1446	1448	1450	1452	1454	1456	1458	1460	1462	0	1	1	1	1	2	2	2	2
21	1464	1466	1468	1470	1472	1474	1476	1478	1480	1482	0	1	1	1	1	2	2	2	2
22	1484	1486	1488	1490	1492	1494	1496	1498	1500	1502	0	1	1	1	1	2	2	2	2
23	1504	1506	1508	1510	1512	1514	1516	1518	1520	1522	0	1	1	1	1	2	2	2	2
24	1524	1526	1528	1530	1532	1534	1536	1538	1540	1542	0	1	1	1	1	2	2	2	2
25	1544	1546	1548	1550	1552	1554	1556	1558	1560	1562	0	1	1	1	1	2	2	2	2
26	1564	1566	1568	1570	1572	1574	1576	1578	1580	1582	0	1	1	1	1	2	2	2	2
27	1584	1586	1588	1590	1592	1594	1596	1598	1600	1602	0	1	1	1	1	2	2	2	2
28	1604	1606	1608	1610	1612	1614	1616	1618	1620	1622	0	1	1	1	1	2	2	2	2
29	1624	1626	1628	1630	1632	1634	1636	1638	1640	1642	0	1	1	1	1	2	2	2	2
30	1644	1646	1648	1650	1652	1654	1656	1658	1660	1662	0	1	1	1	1	2	2	2	2
31	1664	1666	1668	1670	1672	1674	1676	1678	1680	1682	0	1	1	1	1	2	2	2	2
32	1684	1686	1688	1690	1692	1694	1696	1698	1700	1702	0	1	1	1	1	2	2	2	2
33	1704	1706	1708	1710	1712	1714	1716	1718	1720	1722	0	1	1	1	1	2	2	2	2
34	1724	1726	1728	1730	1732	1734	1736	1738	1740	1742	0	1	1	1	1	2	2	2	2
35	1744	1746	1748	1750	1752	1754	1756	1758	1760	1762	0	1	1	1	1	2	2	2	2
36	1764	1766	1768	1770	1772	1774	1776	1778	1780	1782	0	1	1	1	1	2	2	2	2
37	1784	1786	1788	1790	1792	1794	1796	1798	1800	1802	0	1	1	1	1	2	2	2	2
38	1804	1806	1808	1810	1812	1814	1816	1818	1820	1822	0	1	1	1	1	2	2	2	2
39	1824	1826	1828	1830	1832	1834	1836	1838	1840	1842	0	1	1	1	1	2	2	2	2
40	1844	1846	1848	1850	1852	1854	1856	1858	1860	1862	0	1	1	1	1	2	2	2	2
41	1864	1866	1868	1870	1872	1874	1876	1878	1880	1882	0	1	1	1	1	2	2	2	2
42	1884	1886	1888	1890	1892	1894	1896	1898	1900	1902	0	1	1	1	1	2	2	2	2
43	1904	1906	1908	1910	1912	1914	1916	1918	1920	1922	0	1	1	1	1	2	2	2	2
44	1924	1926	1928	1930	1932	1934	1936	1938	1940	1942	0	1	1	1	1	2	2	2	2
45	1944	1946	1948	1950	1952	1954	1956	1958	1960	1962	0	1	1	1	1	2	2	2	2
46	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982	0	1	1	1	1	2	2	2	2
47	1984	1986	1988	1990	1992	1994	1996	1998	2000	2002	0	1	1	1	1	2	2	2	2
48	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	0	1	1	1	1	2	2	2	2
49	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	0	1	1	1	1	2	2	2	2
50	2044	2046	2048	2050	2052	2054	2056	2058	2060	2062	0	1	1	1	1	2	2	2	2
51	2064	2066	2068	2070	2072	2074	2076	2078	2080	2082	0	1	1	1	1	2	2	2	2
52	2084	2086	2088	2090	2092	2094	2096	2098	2100	2102	0	1	1	1	1	2	2	2	2
53	2104	2106	2108	2110	2112	2114	2116	2118	2120	2122	0	1	1	1	1	2	2	2	2
54	2124	2126	2128	2130	2132	2134	2136	2138	2140	2142	0	1	1	1	1	2	2	2	2
55	2144	2146	2148	2150	2152	2154	2156	2158	2160	2162	0	1	1	1	1	2	2	2	2
56	2164	2166	2168	2170	2172	2174	2176	2178	2180	2182	0	1	1	1	1	2	2	2	2
57	2184	2186	2188	2190	2192	2194	2196	2198	2200	2202	0	1	1	1	1	2	2	2	2
58	2204	2206	2208	2210	2212	2214	2216	2218	2220	2222	0	1	1	1	1	2	2	2	2
59	2224	2226	2228	2230	2232	2234	2236	2238	2240	2242	0	1	1	1	1	2	2	2	2
60	2244	2246	2248	2250	2252	2254	2256	2258	2260	2262	0	1	1	1	1	2	2	2	2
61	2264	2266	2268	2270	2272	2274	2276	2278	2280	2282	0	1	1	1	1	2	2	2	2
62	2284	2286	2288	2290	2292	2294	2296	2298	2300	2302	0	1	1	1	1	2	2	2	2
63	2304	2306	2308	2310	2312	2314	2316	2318	2320	2322	0	1	1	1	1	2	2	2	2
64	2324	2326	2328	2330	2332	2334	2336	2338	2340	2342	0	1	1	1	1	2	2	2	2
65	2344	2346	2348	2350	2352	2354	2356	2358	2360	2362	0	1	1	1	1	2	2	2	2
66	2364	2366	2368	2370	2372	2374	2376	2378	2380	2382	0	1	1	1	1	2	2	2	2
67	2384	2386	2388	2390	2392	2394	2396	2398	2400	2402	0	1	1	1	1	2	2	2	2
68	2404	2406	2408	2410	2412	2414	2416	2418	2420	2422	0	1	1	1	1	2	2	2	2
69	2424	2426	2428	2430	2432	2434	2436	2438	2440	2442	0	1	1	1	1	2	2	2	2
70	2444	2446	2448	2450	2452	2454	2456	2458	2460	2462	0	1	1	1	1	2	2	2	2
71	2464	2466	2468	2470	2472	2474	2476	2478	2480	2482	0	1	1	1	1	2	2	2	2
72	2484	2486	2488	2490	2492	2494	2496	2498	2500	2502	0	1	1	1	1	2	2	2	2
73	2504	2506	2508	2510	2512	2514	2516	2518	2520	2522	0	1	1	1	1	2	2	2	2
74	2524	2526	2528	2530	2532	2534	2536	2538	2540	2542	0	1	1	1	1	2	2	2	2
75	2544	2546	2548	2550	2552	2554	2556	2558	2560	2562	0	1	1	1	1	2	2	2	2
76	2564	2566	2568	2570	2572	2574	2576	2578	2580	2582	0	1	1	1	1	2	2	2	2
77	2584	2586	2588	2590	2592	2594	2596	2598	2600	2602	0								

## ANTI-LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	1192	1170	1177	1184	1192	1199	1206	1214	1221	1229	1	1	1	1	4	4	5	6	7
51	1230	1243	1251	1259	1266	1273	1281	1289	1296	1304	1	2	2	3	4	5	6	6	7
52	1311	1318	1327	1334	1342	1350	1357	1365	1373	1381	1	2	3	4	5	6	6	7	7
53	1388	1396	1404	1412	1420	1428	1436	1444	1451	1459	1	2	3	4	5	6	6	7	7
54	1467	1475	1483	1491	1499	1507	1515	1523	1531	1539	1	2	3	4	5	6	6	7	7
55	1547	1555	1563	1571	1579	1587	1595	1603	1611	1619	1	2	3	4	5	6	6	7	7
56	1628	1636	1644	1652	1660	1668	1676	1684	1692	1700	1	2	3	4	5	6	6	7	7
57	1711	1719	1727	1735	1743	1751	1759	1767	1775	1783	1	2	3	4	5	6	6	7	7
58	1792	1800	1808	1816	1824	1832	1840	1848	1856	1864	1	2	3	4	5	6	6	7	7
59	1872	1880	1888	1896	1904	1912	1920	1928	1936	1944	1	2	3	4	5	6	6	7	7
60	1952	1960	1968	1976	1984	1992	2000	2008	2016	2024	1	2	3	4	5	6	6	7	7
61	2032	2040	2048	2056	2064	2072	2080	2088	2096	2104	1	2	3	4	5	6	6	7	7
62	2112	2120	2128	2136	2144	2152	2160	2168	2176	2184	1	2	3	4	5	6	6	7	7
63	2192	2200	2208	2216	2224	2232	2240	2248	2256	2264	1	2	3	4	5	6	6	7	7
64	2272	2280	2288	2296	2304	2312	2320	2328	2336	2344	1	2	3	4	5	6	6	7	7
65	2352	2360	2368	2376	2384	2392	2400	2408	2416	2424	1	2	3	4	5	6	6	7	7
66	2432	2440	2448	2456	2464	2472	2480	2488	2496	2504	1	2	3	4	5	6	6	7	7
67	2512	2520	2528	2536	2544	2552	2560	2568	2576	2584	1	2	3	4	5	6	6	7	7
68	2592	2600	2608	2616	2624	2632	2640	2648	2656	2664	1	2	3	4	5	6	6	7	7
69	2672	2680	2688	2696	2704	2712	2720	2728	2736	2744	1	2	3	4	5	6	6	7	7
70	2752	2760	2768	2776	2784	2792	2800	2808	2816	2824	1	2	3	4	5	6	6	7	7
71	2832	2840	2848	2856	2864	2872	2880	2888	2896	2904	1	2	3	4	5	6	6	7	7
72	2912	2920	2928	2936	2944	2952	2960	2968	2976	2984	1	2	3	4	5	6	6	7	7
73	2992	3000	3008	3016	3024	3032	3040	3048	3056	3064	1	2	3	4	5	6	6	7	7
74	3072	3080	3088	3096	3104	3112	3120	3128	3136	3144	1	2	3	4	5	6	6	7	7
75	3152	3160	3168	3176	3184	3192	3200	3208	3216	3224	1	2	3	4	5	6	6	7	7
76	3232	3240	3248	3256	3264	3272	3280	3288	3296	3304	1	2	3	4	5	6	6	7	7
77	3312	3320	3328	3336	3344	3352	3360	3368	3376	3384	1	2	3	4	5	6	6	7	7
78	3392	3400	3408	3416	3424	3432	3440	3448	3456	3464	1	2	3	4	5	6	6	7	7
79	3472	3480	3488	3496	3504	3512	3520	3528	3536	3544	1	2	3	4	5	6	6	7	7
80	3552	3560	3568	3576	3584	3592	3600	3608	3616	3624	1	2	3	4	5	6	6	7	7
81	3632	3640	3648	3656	3664	3672	3680	3688	3696	3704	1	2	3	4	5	6	6	7	7
82	3712	3720	3728	3736	3744	3752	3760	3768	3776	3784	1	2	3	4	5	6	6	7	7
83	3792	3800	3808	3816	3824	3832	3840	3848	3856	3864	1	2	3	4	5	6	6	7	7
84	3872	3880	3888	3896	3904	3912	3920	3928	3936	3944	1	2	3	4	5	6	6	7	7
85	3952	3960	3968	3976	3984	3992	4000	4008	4016	4024	1	2	3	4	5	6	6	7	7
86	4032	4040	4048	4056	4064	4072	4080	4088	4096	4104	1	2	3	4	5	6	6	7	7
87	4112	4120	4128	4136	4144	4152	4160	4168	4176	4184	1	2	3	4	5	6	6	7	7
88	4192	4200	4208	4216	4224	4232	4240	4248	4256	4264	1	2	3	4	5	6	6	7	7
89	4272	4280	4288	4296	4304	4312	4320	4328	4336	4344	1	2	3	4	5	6	6	7	7
90	4352	4360	4368	4376	4384	4392	4400	4408	4416	4424	1	2	3	4	5	6	6	7	7
91	4432	4440	4448	4456	4464	4472	4480	4488	4496	4504	1	2	3	4	5	6	6	7	7
92	4512	4520	4528	4536	4544	4552	4560	4568	4576	4584	1	2	3	4	5	6	6	7	7
93	4592	4600	4608	4616	4624	4632	4640	4648	4656	4664	1	2	3	4	5	6	6	7	7
94	4672	4680	4688	4696	4704	4712	4720	4728	4736	4744	1	2	3	4	5	6	6	7	7
95	4752	4760	4768	4776	4784	4792	4800	4808	4816	4824	1	2	3	4	5	6	6	7	7
96	4832	4840	4848	4856	4864	4872	4880	4888	4896	4904	1	2	3	4	5	6	6	7	7
97	4912	4920	4928	4936	4944	4952	4960	4968	4976	4984	1	2	3	4	5	6	6	7	7
98	4992	5000	5008	5016	5024	5032	5040	5048	5056	5064	1	2	3	4	5	6	6	7	7
99	5072	5080	5088	5096	5104	5112	5120	5128	5136	5144	1	2	3	4	5	6	6	7	7

SQUARES OF NUMBERS FROM 1 TO 10,000, CORRECT TO FOUR  
SIGNIFICANT FIGURES.

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11	1210	1232	1254	1277	1299	1321	1343	1365	1387	1409	1431	1453	1475	1497	1519	1541	1563	1585	1607	1629
12	1440	1464	1488	1512	1536	1560	1584	1608	1632	1656	1680	1704	1728	1752	1776	1800	1824	1848	1872	1896
13	1690	1716	1742	1768	1794	1820	1846	1872	1898	1924	1950	1976	2002	2028	2054	2080	2106	2132	2158	2184
14	1990	2017	2044	2071	2098	2125	2152	2179	2206	2233	2260	2287	2314	2341	2368	2395	2422	2449	2476	2503
15	2250	2277	2304	2331	2358	2385	2412	2439	2466	2493	2520	2547	2574	2601	2628	2655	2682	2709	2736	2763
16	2580	2607	2634	2661	2688	2715	2742	2769	2796	2823	2850	2877	2904	2931	2958	2985	3012	3039	3066	3093
17	2880	2907	2934	2961	2988	3015	3042	3069	3096	3123	3150	3177	3204	3231	3258	3285	3312	3339	3366	3393
18	3180	3207	3234	3261	3288	3315	3342	3369	3396	3423	3450	3477	3504	3531	3558	3585	3612	3639	3666	3693
19	3480	3507	3534	3561	3588	3615	3642	3669	3696	3723	3750	3777	3804	3831	3858	3885	3912	3939	3966	3993
20	3800	3827	3854	3881	3908	3935	3962	3989	4016	4043	4070	4097	4124	4151	4178	4205	4232	4259	4286	4313
21	4120	4147	4174	4201	4228	4255	4282	4309	4336	4363	4390	4417	4444	4471	4498	4525	4552	4579	4606	4633
22	4360	4387	4414	4441	4468	4495	4522	4549	4576	4603	4630	4657	4684	4711	4738	4765	4792	4819	4846	4873
23	4680	4707	4734	4761	4788	4815	4842	4869	4896	4923	4950	4977	5004	5031	5058	5085	5112	5139	5166	5193
24	4960	4987	5014	5041	5068	5095	5122	5149	5176	5203	5230	5257	5284	5311	5338	5365	5392	5419	5446	5473
25	5280	5307	5334	5361	5388	5415	5442	5469	5496	5523	5550	5577	5604	5631	5658	5685	5712	5739	5766	5793
26	5560	5587	5614	5641	5668	5695	5722	5749	5776	5803	5830	5857	5884	5911	5938	5965	5992	6019	6046	6073
27	5880	5907	5934	5961	5988	6015	6042	6069	6096	6123	6150	6177	6204	6231	6258	6285	6312	6339	6366	6393
28	6160	6187	6214	6241	6268	6295	6322	6349	6376	6403	6430	6457	6484	6511	6538	6565	6592	6619	6646	6673
29	6480	6507	6534	6561	6588	6615	6642	6669	6696	6723	6750	6777	6804	6831	6858	6885	6912	6939	6966	6993
30	6760	6787	6814	6841	6868	6895	6922	6949	6976	7003	7030	7057	7084	7111	7138	7165	7192	7219	7246	7273
31	7080	7107	7134	7161	7188	7215	7242	7269	7296	7323	7350	7377	7404	7431	7458	7485	7512	7539	7566	7593
32	7360	7387	7414	7441	7468	7495	7522	7549	7576	7603	7630	7657	7684	7711	7738	7765	7792	7819	7846	7873
33	7680	7707	7734	7761	7788	7815	7842	7869	7896	7923	7950	7977	8004	8031	8058	8085	8112	8139	8166	8193
34	7960	7987	8014	8041	8068	8095	8122	8149	8176	8203	8230	8257	8284	8311	8338	8365	8392	8419	8446	8473
35	8280	8307	8334	8361	8388	8415	8442	8469	8496	8523	8550	8577	8604	8631	8658	8685	8712	8739	8766	8793
36	8560	8587	8614	8641	8668	8695	8722	8749	8776	8803	8830	8857	8884	8911	8938	8965	8992	9019	9046	9073
37	8880	8907	8934	8961	8988	9015	9042	9069	9096	9123	9150	9177	9204	9231	9258	9285	9312	9339	9366	9393
38	9160	9187	9214	9241	9268	9295	9322	9349	9376	9403	9430	9457	9484	9511	9538	9565	9592	9619	9646	9673
39	9480	9507	9534	9561	9588	9615	9642	9669	9696	9723	9750	9777	9804	9831	9858	9885	9912	9939	9966	9993
40	9760	9787	9814	9841	9868	9895	9922	9949	9976	10003	10030	10057	10084	10111	10138	10165	10192	10219	10246	10273
41	10080	10107	10134	10161	10188	10215	10242	10269	10296	10323	10350	10377	10404	10431	10458	10485	10512	10539	10566	10593
42	10360	10387	10414	10441	10468	10495	10522	10549	10576	10603	10630	10657	10684	10711	10738	10765	10792	10819	10846	10873
43	10680	10707	10734	10761	10788	10815	10842	10869	10896	10923	10950	10977	11004	11031	11058	11085	11112	11139	11166	11193
44	10960	10987	11014	11041	11068	11095	11122	11149	11176	11203	11230	11257	11284	11311	11338	11365	11392	11419	11446	11473
45	11280	11307	11334	11361	11388	11415	11442	11469	11496	11523	11550	11577	11604	11631	11658	11685	11712	11739	11766	11793
46	11560	11587	11614	11641	11668	11695	11722	11749	11776	11803	11830	11857	11884	11911	11938	11965	11992	12019	12046	12073
47	11880	11907	11934	11961	11988	12015	12042	12069	12096	12123	12150	12177	12204	12231	12258	12285	12312	12339	12366	12393
48	12160	12187	12214	12241	12268	12295	12322	12349	12376	12403	12430	12457	12484	12511	12538	12565	12592	12619	12646	12673
49	12480	12507	12534	12561	12588	12615	12642	12669	12696	12723	12750	12777	12804	12831	12858	12885	12912	12939	12966	12993
50	12800	12827	12854	12881	12908	12935	12962	12989	13016	13043	13070	13097	13124	13151	13178	13205	13232	13259	13286	13313
51	13120	13147	13174	13201	13228	13255	13282	13309	13336	13363	13390	13417	13444	13471	13498	13525	13552	13579	13606	13633
52	13440	13467	13494	13521	13548	13575	13602	13629	13656	13683	13710	13737	13764	13791	13818	13845	13872	13899	13926	13953
53	13760	13787	13814	13841	13868	13895	13922	13949	13976	14003	14030	14057	14084	14111	14138	14165	14192	14219	14246	14273
54	14080	14107	14134	14161	14188	14215	14242	14269	14296	14323	14350	14377	14404	14431	14458	14485	14512	14539	14566	14593
55	14360	14387	14414	14441	14468	14495	14522	14549	14576	14603	14630	14657	14684	14711	14738	14765	14792	14819	14846	14873
56	14680	14707	14734	14761	14788	14815	14842	14869	14896	14923	14950	14977	15004	15031	15058	15085	15112	15139	15166	15193
57	14960	14987	15014	15041	15068	15095	15122	15149	15176	15203	15230	15257	15284	15311	15338	15365	15392	15419	15446	15473
58	15280	15307	15334	15361	15388	15415	15442	15469	15496	15523	15550	15577	15604	15631	15658	15685	15712	15739	15766	15793
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60	15880	15907	15934	15961	15988	16015	16042	16069	16096	16123	16150	16177	16204	16231	16258	16285	16312	16339	16366	16393
61	16160	16187	16214	16241	16268	16295	16322	16349	16376	16403	16430	16457	16484	16511	16538	16565	16592	16619	16646	16673
62	16480	16507	16534	16561	16588	16615	16642	16669	16696	16723	16750	16777	16804	16831	16858	16885	16912	16939	16966	16993
63	16760	16787	16814	16841	16868	16895	16922	16949	16976	17003	17030	17057	17084	17111	17138	17165	17192	17219	17246	17273
64	17080	17107	17134	17161	17188	17215	17242	17269	17296	17323	17350	17377	17404	17431	17458	17485	17512	17539	17566	17593
65	17360	17387	17414	17441	17468	17495	17522	17549	17576	17603	17630	17657	17684	17711	17738	17765	17792	17819	17846	17873
66	17680	17707	17734	17761	17788	17815	17842	17869	17896	17923	17950	17977	18004	18031	18058	18085	18112	18139	18166	18193
67	17960	17987	18014	18041	18068	18095	18122	18149	18176	18203	18230	18257	18284	18311	18338	18365	18392	18419	18446	18473
68	18280	18307	18334	18361	18388	18415	18442	18469	18496	18523	18550	18577	18604	18631	18658	18685	18712	18739	18766	18793
69	18560	18587	18614	18641	18668	18695	18722	18749	18776	18803	18830	18857	18884	18911	18938	18965	18992			

SQUARES OF NUMBERS FROM 1 TO 10,000, CORRECT TO FOUR  
SIGNIFICANT FIGURES.

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46	2116	2147	2178	2209	2240	2271	2302	2333	2364	2395	2426	2457	2488	2519	2550	2581	2612	2643	2674	2705	2736
47	2209	2240	2271	2302	2333	2364	2395	2426	2457	2488	2519	2550	2581	2612	2643	2674	2705	2736	2767	2798	2829
48	2304	2335	2366	2397	2428	2459	2490	2521	2552	2583	2614	2645	2676	2707	2738	2769	2800	2831	2862	2893	2924
49	2401	2432	2463	2494	2525	2556	2587	2618	2649	2680	2711	2742	2773	2804	2835	2866	2897	2928	2959	2990	3021
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54	2836	2867	2898	2929	2960	2991	3022	3053	3084	3115	3146	3177	3208	3239	3270	3301	3332	3363	3394	3425	3456
55	2925	2956	2987	3018	3049	3080	3111	3142	3173	3204	3235	3266	3297	3328	3359	3390	3421	3452	3483	3514	3545
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62	3604	3635	3666	3697	3728	3759	3790	3821	3852	3883	3914	3945	3976	4007	4038	4069	4100	4131	4162	4193	4224
63	3709	3740	3771	3802	3833	3864	3895	3926	3957	3988	4019	4050	4081	4112	4143	4174	4205	4236	4267	4298	4329
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65	3925	3956	3987	4018	4049	4080	4111	4142	4173	4204	4235	4266	4297	4328	4359	4390	4421	4452	4483	4514	4545
66	4028	4059	4090	4121	4152	4183	4214	4245	4276	4307	4338	4369	4400	4431	4462	4493	4524	4555	4586	4617	4648
67	4136	4167	4198	4229	4260	4291	4322	4353	4384	4415	4446	4477	4508	4539	4570	4601	4632	4663	4694	4725	4756
68	4246	4277	4308	4339	4370	4401	4432	4463	4494	4525	4556	4587	4618	4649	4680	4711	4742	4773	4804	4835	4866
69	4359	4390	4421	4452	4483	4514	4545	4576	4607	4638	4669	4700	4731	4762	4793	4824	4855	4886	4917	4948	4979
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71	4596	4627	4658	4689	4720	4751	4782	4813	4844	4875	4906	4937	4968	4999	5030	5061	5092	5123	5154	5185	5216
72	4718	4749	4780	4811	4842	4873	4904	4935	4966	4997	5028	5059	5090	5121	5152	5183	5214	5245	5276	5307	5338
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77	5384	5415	5446	5477	5508	5539	5570	5601	5632	5663	5694	5725	5756	5787	5818	5849	5880	5911	5942	5973	6004
78	5516	5547	5578	5609	5640	5671	5702	5733	5764	5795	5826	5857	5888	5919	5950	5981	6012	6043	6074	6105	6136
79	5650	5681	5712	5743	5774	5805	5836	5867	5898	5929	5960	5991	6022	6053	6084	6115	6146	6177	6208	6239	6270
80	5786	5817	5848	5879	5910	5941	5972	6003	6034	6065	6096	6127	6158	6189	6220	6251	6282	6313	6344	6375	6406
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82	6064	6095	6126	6157	6188	6219	6250	6281	6312	6343	6374	6405	6436	6467	6498	6529	6560	6591	6622	6653	6684
83	6204	6235	6266	6297	6328	6359	6390	6421	6452	6483	6514	6545	6576	6607	6638	6669	6700	6731	6762	6793	6824
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86	6636	6667	6698	6729	6760	6791	6822	6853	6884	6915	6946	6977	7008	7039	7070	7101	7132	7163	7194	7225	7256
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88	6932	6963	6994	7025	7056	7087	7118	7149	7180	7211	7242	7273	7304	7335	7366	7397	7428	7459	7490	7521	7552
89	7082	7113	7144	7175	7206	7237	7268	7299	7330	7361	7392	7423	7454	7485	7516	7547	7578	7609	7640	7671	7702
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93	7692	7723	7754	7785	7816	7847	7878	7909	7940	7971	8002	8033	8064	8095	8126	8157	8188	8219	8250	8281	8312
94	7842	7873	7904	7935	7966	7997	8028	8059	8090	8121	8152	8183	8214	8245	8276	8307	8338	8369	8400	8431	8462
95	8094	8125	8156	8187	8218	8249	8280	8311	8342	8373	8404	8435	8466	8497	8528	8559	8590	8621	8652	8683	8714
96	8266	8297	8328	8359	8390	8421	8452	8483	8514	8545	8576	8607	8638	8669	8700	8731	8762	8793	8824	8855	8886
97	8418	8449	8480	8511	8542	8573	8604	8635	8666	8697	8728	8759	8790	8821	8852	8883	8914	8945	8976	9007	9038
98	8572	8603	8634	8665	8696	8727	8758	8789	8820	8851	8882	8913	8944	8975	9006	9037	9068	9099	9130	9161	9192
99	8728	8759	8790	8821	8852	8883	8914	8945	8976	9007	9038	9069	9100	9131	9162	9193	9224	9255	9286	9317	9348
100	8886	8917	8948	8979	9010	9041	9072	9103	9134	9165	9196	9227	9258	9289	9320	9351	9382	9413	9444	9475	9506
101	9054	9085	9116	9147	9178	9209	9240	9271	9302	9333	9364	9395	9426	9457	9488	9519	9550	9581	9612	9643	9674
102	9216	9247	9278	9309	9340	9371	9402	9433	9464	9495	9526	9557	9588	9619	9650	9681	9712	9743	9774	9805	9836
103	9382	9413	9444	9475	9506	9537	9568	9599	9630	9661	9692	9723	9754	9785	9816	9847	9878	9909	9940	9971	10002
104	9544	9575	9606	9637	9668	9699	9730	9761	9792	9823	9854	9885	9916	9947	9978	10009	10040	10071	10102	10133	10164

## RECIPROCAL OF NUMBERS FROM 1 TO 9999.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
10	0000	0001	0004	0006	0010	0012	0014	0018	0019	0020	0021	0022	0023	0024	0025	0026	0027	0028	0029	0030	0031	0032	0033	0034	0035	0036	0037	0038	0039	0040	0041	0042	0043	0044	0045	0046	0047	0048	0049	0050	0051	0052	0053	0054	0055	0056	0057	0058	0059	0060	0061	0062	0063	0064	0065	0066	0067	0068	0069	0070	0071	0072	0073	0074	0075	0076	0077	0078	0079	0080	0081	0082	0083	0084	0085	0086	0087	0088	0089	0090	0091	0092	0093	0094	0095	0096	0097	0098	0099	0100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
11	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0099	0

Reciprocals from 1 to 1000

Reciprocals from 1001 to 10000

to 10000

to 10000

Note.—Numbers in difference columns to be subtracted, not added.



## RECIPROCAL OF NUMBERS FROM 1 TO 9999.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
56	1816	1810	1812	1806	1805	1802	1799	1795	1793	1789	1	1	2	2	2	2	2	2	2
57	1786	1783	1779	1778	1773	1770	1767	1764	1761	1757	1	1	1	1	1	1	1	1	1
58	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	0	7	1	1	1	1	1	1	1
59	1724	1721	1718	1715	1712	1709	1706	1704	1701	1696	0	0	1	1	1	1	1	1	1
60	1695	1692	1689	1686	1683	1681	1678	1675	1672	1669	1	1	1	2	2	2	2	2	2
61	1667	1664	1661	1658	1655	1653	1650	1647	1645	1642	0	1	1	1	1	1	1	1	1
62	1639	1637	1634	1631	1629	1626	1623	1621	1618	1615	0	1	1	1	1	1	1	1	1
63	1613	1610	1606	1603	1600	1597	1593	1592	1590	1587	0	1	1	1	1	1	1	1	1
64	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	1	1	1	1	1	1	1	1	1
65	1563	1560	1559	1556	1553	1550	1548	1545	1543	1541	0	0	0	1	1	1	1	1	1
66	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	1	1	1	1	1	1	1	1	1
67	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	1	1	1	1	1	1	1	1	1
68	1495	1490	1488	1486	1484	1483	1479	1477	1475	1473	0	0	0	0	1	1	1	1	1
69	1471	1469	1466	1463	1461	1459	1456	1453	1451	1449	0	1	1	1	1	1	1	1	1
70	1446	1447	1445	1443	1441	1439	1437	1435	1433	1431	0	1	1	1	1	1	1	1	1
71	1426	1427	1425	1423	1420	1418	1415	1413	1411	1410	0	0	0	0	1	1	1	1	1
72	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	1	1	1	1	1	1	1	1	1
73	1390	1387	1385	1383	1381	1379	1377	1375	1374	1373	0	0	0	0	1	1	1	1	1
74	1373	1369	1367	1364	1362	1361	1359	1357	1355	1353	0	0	0	0	0	1	1	1	1
75	1351	1348	1346	1344	1342	1340	1338	1337	1335	1333	0	0	0	0	0	1	1	1	1
76	1330	1328	1326	1324	1322	1320	1318	1317	1315	1313	0	0	0	0	0	1	1	1	1
77	1310	1308	1306	1304	1302	1300	1298	1297	1295	1293	0	0	0	0	0	1	1	1	1
78	1290	1287	1285	1283	1281	1279	1277	1275	1274	1273	0	0	0	0	0	1	1	1	1
79	1271	1269	1267	1265	1263	1261	1259	1257	1255	1253	0	1	1	1	1	1	1	1	1
80	1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	0	0	0	0	1	1	1	1	1
81	1235	1233	1232	1230	1229	1227	1226	1224	1222	1221	0	0	1	1	1	1	1	1	1
82	1220	1218	1217	1215	1214	1212	1211	1209	1208	1206	0	0	0	1	1	1	1	1	1
83	1205	1203	1202	1200	1199	1196	1195	1193	1192	1191	1	1	1	1	1	1	1	1	1
84	1190	1189	1188	1186	1185	1183	1182	1181	1179	1178	0	0	0	0	1	1	1	1	1
85	1176	1175	1174	1173	1171	1170	1168	1167	1166	1164	0	0	0	0	0	1	1	1	1
86	1163	1161	1160	1159	1157	1156	1155	1153	1152	1151	0	0	0	1	1	1	1	1	1
87	1149	1148	1147	1146	1144	1143	1142	1140	1139	1138	0	1	1	1	1	1	1	1	1
88	1136	1135	1134	1133	1131	1130	1129	1127	1126	1125	0	1	1	1	1	1	1	1	1
89	1124	1123	1121	1120	1119	1117	1116	1115	1114	1112	0	0	0	0	0	1	1	1	1
90	1111	1110	1109	1107	1106	1105	1104	1103	1101	1100	0	0	0	1	1	1	1	1	1
91	1099	1098	1096	1095	1094	1093	1092	1091	1089	1088	0	0	1	1	1	1	1	1	1
92	1087	1086	1085	1084	1082	1081	1080	1079	1078	1076	0	0	0	0	1	1	1	1	1
93	1075	1074	1073	1072	1071	1070	1069	1067	1066	1065	0	0	0	0	0	1	1	1	1
94	1064	1063	1062	1060	1059	1058	1057	1056	1055	1054	0	0	0	0	0	1	1	1	1
95	1053	1052	1050	1049	1048	1047	1046	1045	1044	1043	0	0	0	0	1	1	1	1	1
96	1042	1041	1040	1038	1037	1036	1035	1034	1033	1032	0	0	0	0	0	1	1	1	1
97	1031	1030	1029	1028	1027	1026	1025	1024	1023	1021	1	1	1	1	1	1	1	1	1
98	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	0	0	0	0	0	1	1	1	1
99	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	0	0	0	0	1	1	1	1	1

Reciprocals from 2 to 10 = 0'

" " 11 to 100 = 0'

Reciprocals from 101 to 1000 = 0'00

" " 1001 to 9999 = 0'000

NOTE.—Numbers in difference columns to be subtracted, not added.

TABLE OF DOUBLED SQUARE ROOTS FOR

	0	100	200	300	400	500	600	700	800	900	
0	0.000	20.00	38.38	54.64	69.00	81.78	92.50	101.50	108.90	114.90	0
1	2.000	20.10	38.48	54.70	69.06	81.84	92.56	101.56	108.96	114.96	1
2	4.000	20.20	38.58	54.80	69.16	81.94	92.66	101.66	109.06	115.06	2
3	6.000	20.30	38.68	54.90	69.26	82.04	92.76	101.76	109.16	115.16	3
4	8.000	20.40	38.78	55.00	69.36	82.12	92.86	101.86	109.26	115.26	4
5	10.000	20.50	38.88	55.10	69.46	82.20	92.96	101.96	109.36	115.36	5
6	12.000	20.60	38.98	55.20	69.56	82.28	93.06	102.06	109.46	115.46	6
7	14.000	20.70	39.08	55.30	69.66	82.36	93.16	102.16	109.56	115.56	7
8	16.000	20.80	39.18	55.40	69.76	82.44	93.26	102.26	109.66	115.66	8
9	18.000	20.90	39.28	55.50	69.86	82.52	93.36	102.36	109.76	115.76	9
10	20.000	21.00	39.38	55.60	69.96	82.60	93.46	102.46	109.86	115.86	10
11	22.000	21.10	39.48	55.70	70.06	82.68	93.56	102.56	109.96	115.96	11
12	24.000	21.20	39.58	55.80	70.16	82.76	93.66	102.66	110.06	116.06	12
13	26.000	21.30	39.68	55.90	70.26	82.84	93.76	102.76	110.16	116.16	13
14	28.000	21.40	39.78	56.00	70.36	82.92	93.86	102.86	110.26	116.26	14
15	30.000	21.50	39.88	56.10	70.46	83.00	93.96	102.96	110.36	116.36	15
16	32.000	21.60	39.98	56.20	70.56	83.08	94.06	103.06	110.46	116.46	16
17	34.000	21.70	40.08	56.30	70.66	83.16	94.16	103.16	110.56	116.56	17
18	36.000	21.80	40.18	56.40	70.76	83.24	94.26	103.26	110.66	116.66	18
19	38.000	21.90	40.28	56.50	70.86	83.32	94.36	103.36	110.76	116.76	19
20	40.000	22.00	40.38	56.60	70.96	83.40	94.46	103.46	110.86	116.86	20
21	42.000	22.10	40.48	56.70	71.06	83.48	94.56	103.56	110.96	116.96	21
22	44.000	22.20	40.58	56.80	71.16	83.56	94.66	103.66	111.06	117.06	22
23	46.000	22.30	40.68	56.90	71.26	83.64	94.76	103.76	111.16	117.16	23
24	48.000	22.40	40.78	57.00	71.36	83.72	94.86	103.86	111.26	117.26	24
25	50.000	22.50	40.88	57.10	71.46	83.80	94.96	103.96	111.36	117.36	25
26	52.000	22.60	40.98	57.20	71.56	83.88	95.06	104.06	111.46	117.46	26
27	54.000	22.70	41.08	57.30	71.66	83.96	95.16	104.16	111.56	117.56	27
28	56.000	22.80	41.18	57.40	71.76	84.04	95.26	104.26	111.66	117.66	28
29	58.000	22.90	41.28	57.50	71.86	84.12	95.36	104.36	111.76	117.76	29
30	60.000	23.00	41.38	57.60	71.96	84.20	95.46	104.46	111.86	117.86	30
31	62.000	23.10	41.48	57.70	72.06	84.28	95.56	104.56	111.96	117.96	31
32	64.000	23.20	41.58	57.80	72.16	84.36	95.66	104.66	112.06	118.06	32
33	66.000	23.30	41.68	57.90	72.26	84.44	95.76	104.76	112.16	118.16	33
34	68.000	23.40	41.78	58.00	72.36	84.52	95.86	104.86	112.26	118.26	34
35	70.000	23.50	41.88	58.10	72.46	84.60	95.96	104.96	112.36	118.36	35
36	72.000	23.60	41.98	58.20	72.56	84.68	96.06	105.06	112.46	118.46	36
37	74.000	23.70	42.08	58.30	72.66	84.76	96.16	105.16	112.56	118.56	37
38	76.000	23.80	42.18	58.40	72.76	84.84	96.26	105.26	112.66	118.66	38
39	78.000	23.90	42.28	58.50	72.86	84.92	96.36	105.36	112.76	118.76	39
40	80.000	24.00	42.38	58.60	72.96	85.00	96.46	105.46	112.86	118.86	40
41	82.000	24.10	42.48	58.70	73.06	85.08	96.56	105.56	112.96	118.96	41
42	84.000	24.20	42.58	58.80	73.16	85.16	96.66	105.66	113.06	119.06	42
43	86.000	24.30	42.68	58.90	73.26	85.24	96.76	105.76	113.16	119.16	43
44	88.000	24.40	42.78	59.00	73.36	85.32	96.86	105.86	113.26	119.26	44
45	90.000	24.50	42.88	59.10	73.46	85.40	96.96	105.96	113.36	119.36	45
46	92.000	24.60	42.98	59.20	73.56	85.48	97.06	106.06	113.46	119.46	46
47	94.000	24.70	43.08	59.30	73.66	85.56	97.16	106.16	113.56	119.56	47
48	96.000	24.80	43.18	59.40	73.76	85.64	97.26	106.26	113.66	119.66	48
49	98.000	24.90	43.28	59.50	73.86	85.72	97.36	106.36	113.76	119.76	49
50	100.000	25.00	43.38	59.60	73.96	85.80	97.46	106.46	113.86	119.86	50

## LORD KELVIN'S STANDARD ELECTRIC BALANCE

	0	100	200	300	400	500	600	700	800	900	
51	14-928	24-58	31-89	37-47	42-97	48-06	51-69	54-81	58-34	61-65	51
52	14-922	24-56	31-75	37-33	42-83	47-92	51-55	54-67	58-20	61-51	52
53	14-916	24-74	31-81	37-26	42-57	47-66	51-11	54-23	58-41	61-74	53
54	14-907	24-82	31-87	37-43	42-61	47-67	51-15	54-28	58-45	61-77	54
55	14-902	24-90	31-94	37-58	42-69	47-73	51-19	54-32	58-48	61-81	55
56	14-907	24-98	32-00	37-74	42-71	47-76	51-22	54-36	58-51	61-84	56
57	14-900	25-00	32-00	37-79	42-76	47-79	51-24	54-38	58-53	61-87	57
58	15-028	25-14	32-12	37-84	42-80	47-84	51-26	54-40	58-55	61-90	58
59	15-033	25-22	32-19	37-89	42-85	47-89	51-34	54-48	58-62	61-94	59
60	15-038	25-30	32-25	37-95	42-90	47-93	51-38	54-54	58-68	61-97	60
61	15-030	25-38	32-31	38-00	42-94	47-97	51-42	54-57	58-69	62-00	61
62	15-048	25-44	32-37	38-05	42-99	47-41	51-46	54-61	58-73	62-03	62
63	15-074	25-53	32-46	38-11	43-05	47-46	51-50	54-64	58-75	62-05	63
64	15-090	25-51	32-50	38-16	43-06	47-50	51-54	54-68	58-79	62-08	64
65	15-126	25-59	32-56	38-21	43-12	47-54	51-58	54-72	58-82	62-12	65
66	15-245	25-77	32-62	38-26	43-17	47-58	51-61	54-76	58-86	62-16	66
67	15-271	25-86	32-68	38-31	43-22	47-63	51-65	54-80	58-89	62-19	67
68	15-295	25-92	32-74	38-37	43-27	47-67	51-69	54-84	58-92	62-22	68
69	15-313	25-90	32-80	38-42	43-31	47-71	51-73	54-88	58-95	62-24	69
70	15-323	25-98	32-86	38-47	43-36	47-75	51-77	54-92	58-99	62-28	70
71	15-352	26-16	32-92	38-52	43-41	47-79	51-81	54-96	59-03	62-32	71
72	15-371	26-22	32-98	38-57	43-45	47-83	51-85	54-97	59-05	62-35	72
73	15-388	26-31	33-05	38-63	43-50	47-87	51-88	55-01	59-09	62-39	73
74	15-428	26-36	33-11	38-68	43-54	47-92	51-92	55-04	59-12	62-42	74
75	15-431	26-46	33-17	38-74	43-59	47-96	51-96	55-08	59-16	62-45	75
76	15-436	26-52	33-23	38-78	43-63	48-00	52-00	55-11	59-19	62-48	76
77	15-450	26-61	33-29	38-83	43-68	48-04	52-04	55-15	59-23	62-51	77
78	15-464	26-68	33-35	38-88	43-73	48-08	52-08	55-19	59-26	62-54	78
79	15-476	26-76	33-41	38-94	43-77	48-12	52-12	55-23	59-30	62-58	79
80	15-488	26-88	33-47	38-99	43-82	48-17	52-17	55-26	59-33	62-61	80
81	15-500	26-91	33-53	39-04	43-86	48-21	52-19	55-28	59-35	62-64	81
82	15-511	26-96	33-59	39-09	43-91	48-25	52-22	55-32	59-40	62-67	82
83	15-527	27-06	33-65	39-14	43-95	48-29	52-27	55-36	59-43	62-71	83
84	15-533	27-13	33-70	39-19	44-00	48-33	52-31	55-40	59-46	62-74	84
85	15-535	27-20	33-74	39-24	44-03	48-37	52-35	55-44	59-50	62-77	85
86	15-547	27-28	33-82	39-30	44-08	48-41	52-38	55-47	59-53	62-80	86
87	15-565	27-35	33-88	39-34	44-14	48-46	52-42	55-51	59-57	62-83	87
88	15-573	27-42	33-94	39-40	44-18	48-50	52-46	55-54	59-60	62-86	88
89	15-598	27-53	34-00	39-45	44-23	48-54	52-50	55-58	59-64	62-90	89
90	15-574	27-57	34-06	39-50	44-27	48-58	52-54	55-61	59-67	62-93	90
91	15-578	27-64	34-12	39-55	44-32	48-62	52-57	55-65	59-70	62-96	91
92	15-588	27-71	34-18	39-60	44-36	48-66	52-61	55-68	59-73	62-99	92
93	15-587	27-78	34-23	39-65	44-41	48-70	52-65	55-72	59-77	63-02	93
94	15-591	27-85	34-29	39-70	44-45	48-74	52-69	55-75	59-80	63-05	94
95	15-594	27-88	34-35	39-75	44-50	48-78	52-73	55-79	59-84	63-09	95
96	15-598	28-00	34-41	39-80	44-54	48-82	52-76	55-82	59-87	63-12	96
97	15-599	28-07	34-47	39-85	44-59	48-87	52-80	55-86	59-90	63-15	97
98	15-599	28-14	34-52	39-90	44-63	48-91	52-84	55-90	59-93	63-18	98
99	15-600	28-21	34-58	39-95	44-68	48-95	52-88	55-94	59-97	63-21	99
100	15-600	28-28	34-64	40-00	44-73	48-99	52-92	55-97	59-00	63-25	100